3. UNDERSTANDING THE CHOICES: RELATING WATER QUALITY MANAGEMENT DECISIONS TO CHANGES IN ECOSYSTEMS, ECOSYSTEM SERVICES AND ECOLOGICAL BENEFITS

Existing WQS guidance for evaluating socioeconomic impacts in UAAs and ARs includes analyses of financial impacts on affected entities and regional economic impacts on communities. Nevertheless, states, tribes, and communities could take a broader approach in analyzing the effects of water quality management options (see Chapter 1). A variety of socioeconomic analysis methods can be used (see Chapter 4) to provide decision-makers with a broader understanding of who the relevant stakeholders are and how alternative management options are likely to affect them. Decision-makers must often weigh gains and losses to different groups, and these analytical methods provide them with tools for evaluating the relevant trade-offs.

Chapter 3 provides decision-makers with a general framework for understanding how the choices affect ecosystems and human well-being. It can be used to organize analyses and to characterize conditions for a wide variety of water quality management situations and scenarios. In this chapter, the framework is first described and then illustrated with several hypothetical case study examples.

This chapter combines concepts from ecological risk assessment (ERA), stressor identification, and socioeconomic analyses, such as BCA. Section 3.1 defines water body impairment and describes approaches for identifying impairments and their causes through stressor identification. ERA and stressor identification are two tools that can contribute to UAA, and this section summarizes the main components of ERA and explains how stressor identification can be used to inform ERA in an iterative fashion to compare risks to aquatic ecosystems associated with various mitigation strategies. Section 3.2 extends this framework to show how aquatic ecosystems are linked to and support humans through the provision of "ecosystem services." It defines and categorizes these services and provides examples of how they can be characterized. It also discusses how ecosystem services are related to designated uses.

To further illustrate these connections and show how they can be used to inform use-attainment decisions, Section 3.3 describes relevant socioeconomic endpoints and Section 3.4 develops flow diagrams representing expanded conceptual models. These expanded models include the interconnections between sources, stressors, ecosystem components and processes, and ecological assessment endpoints. They also extend these links to include effects on ecosystem services and related socioeconomic impacts. In addition, they include linkages to management alternatives, showing how these alternatives alter stressor impacts, services, human welfare, and designated use attainment. The models are applied and illustrated through five hypothetical case studies. The main objective in defining these expanded conceptual models is to provide decision-makers with an initial framework to consider for identifying and evaluating a broader range of ecological and socioeconomic endpoints associated with WQS. Most of these endpoints will not otherwise be captured using existing WQS guidance.

3.1. IDENTIFYING IMPAIRMENTS AND THEIR CAUSES

Understanding impairments and their causes is central to establishing appropriate designated uses for water bodies through UAAs and ARs. Thus, the purpose of this section is to

- provide the reader with an understanding of impairments in terms of designated uses and indicators;
- identify the causes of the biological impairment (referred to as stressor identification); and
- use information gleaned from the stressor identification to improve the conceptual models that characterize the relationships among source, stressor, and impairment.

Figure 3-1 adapts the decision framework outlined in Figure 1-6 to specifically convey where in the process stressor identification occurs and how that information is used in improving the conceptual models that compare alternative approaches to address nonattainment. Whereas ERA is a forward-looking process that evaluates the likelihood that adverse ecological effects (such as disease or injury) may occur as a result of exposure to a stressor—a chemical, physical, or biological agent—stressor identification is a retrospective process used to identify which of several possible stressors is most likely causing a water body's observed impairment. Stressor identification can identify the causes of impairment, supporting both the development of proposed management alternatives as well as the improvement of ERA conceptual models

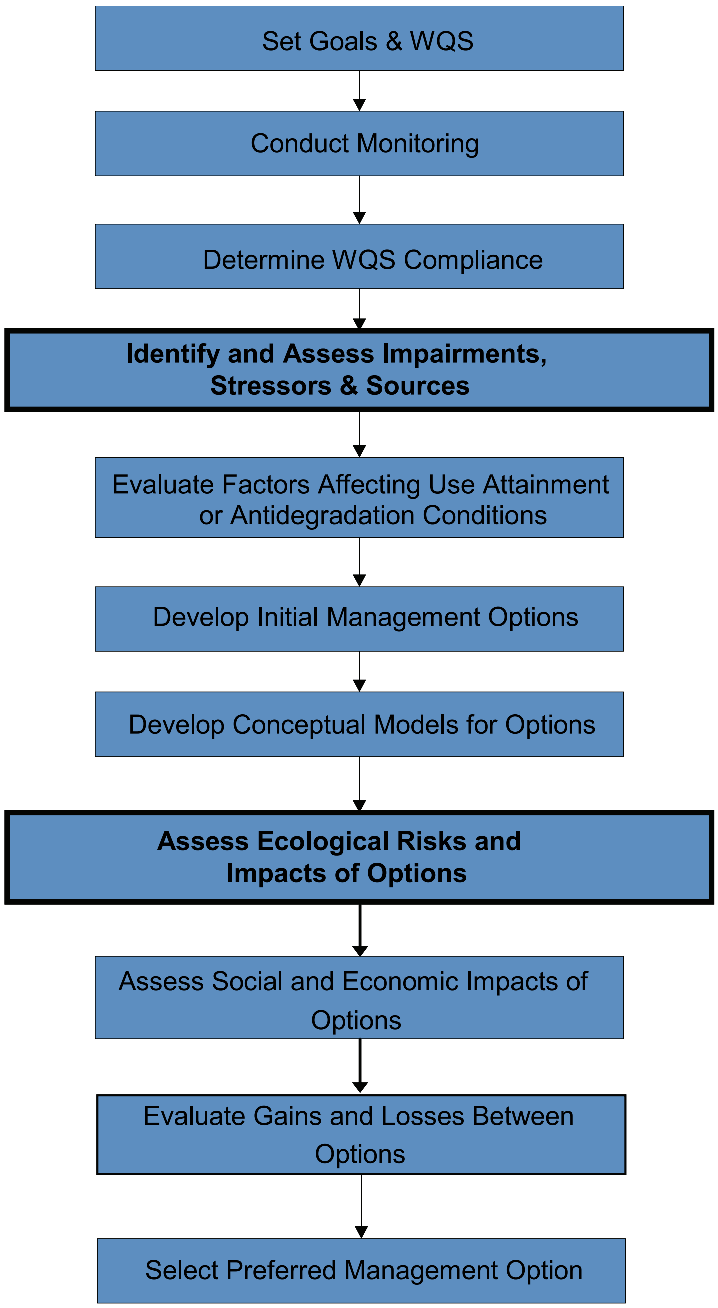


FIGURE 3-1

Relationship of Stressor Identification and Ecological Risk Assessment to the Other Components of Use-Attainment Decisions expanded to describe the relationships among sources, stressors, exposures, responses, and ecosystem services.

Management alternatives can include various voluntary or regulatory actions to reduce the causes or limit the effects of impairment. As described above, the expanded conceptual models can then illustrate the anticipated effects of each of the management alternatives on the ecosystem services. ERA, stressor identification, and socioeconomic analyses then provide the means to characterize and compare the management alternatives to support use-attainment decisions (Bruins et al., 2005).

3.1.1. Impairments

Impairment under the CWA may be broadly defined as any detrimental effect on the integrity of a water body caused by a stressor (or stressors) that prevents attainment of the designated use. The breadth of this definition underscores the importance of characterizing the nature of a detected impairment, including its spatial and temporal scale, and identifying all of its potential causes. Although the focus of this report is not on the detection of impairments, it is important to understand what kinds of impairments are possible, what indicators are used in detecting an impairment, and what sorts of stressors may lead to an impairment.

3.1.1.1. *Types of Impairments*

Because impairments are defined in terms of designated uses, it is useful to think about impairments in a relative sense; that is, the reduction in the quality/quantity of the designated use relative to either the initial conditions (before introduction of a stressor) or a reference water body (i.e., a similar water body where human disturbance is at a minimum). Designated uses cover a wide variety of categories that reflect the biological, chemical, and physical attributes of the water body. Therefore, impairments include a broad range of water body characteristics, including, for example, elevated concentrations of toxics in fish, objectionable odors or low visibility in the water, decreased depth of navigable waters, or reduced flow in agricultural water supplies. Note that all of these impairments are directly linked to designated uses (e.g., elevated fish tissue concentrations of pollutants affect fish consumption), and all are defined in terms of measurable changes in how the water body is used.

3.1.1.2. *Indicators of Impairments*

WQS may use various criteria to indicate impairment. These fall into two major groups: narrative criteria and numeric criteria. Narrative criteria are qualitative descriptions of the conditions within a water body that are necessary to support designated uses such as recreation (e.g., swimming) or aquatic life. Narrative criteria can be in the form of simple statements such as “free from pollutants that produce objectionable color, odor, or taste” or they may be more explicit with respect to biological integrity, toxicity, nuisance algal growths, or settleable solids. Impairment may be determined based on the ability of the water body to support a designated type of fishery (e.g., a river that does not meet narrative WQS because it fails to support adequate salmonid spawning). Narrative criteria are an integral component of states’ WQS, and they are used often to establish water body-specific numerical criteria.

Numeric water quality criteria provide quantitative measures of the “health” of the water body and provide standards that are easily interpretable with respect to impairment. For example, numeric criteria include the Ambient Water Quality Criteria (AWQC) for the protection of health and aquatic life, respectively, from exposure to toxic pollutants. Other numeric criteria include measures of water quality characteristics such as dissolved oxygen (DO) content, pH, and suspended solids; concentrations of nutrients or chlorophyll *a* to indicate overenrichment; and microbial water quality criteria for waterborne bacteria and other pathogens. In addition, biological numeric criteria have been developed to describe the expected attainable community attributes and establish values based on measures such as species richness, presence or absence of indicator taxa, and distribution of classes of organisms. The Index of Biological Integrity (IBI) is an example of a biological numeric criterion for fish community health that combines several specific, quantitative measures of biological components (e.g., number of pollution-intolerant fish species present, percentage of individual fish with deformities) and is used to determine when a water body is impaired. U.S. EPA’s (1994) *Water Quality Standards Handbook* provides a thorough discussion of water quality criteria, and descriptions of ongoing research into developing quantitative water quality criteria are available at http://www.epa.gov/waterscience/standards.

3.1.1.3. *Stressors that Lead to Impairments*

The broad scope of the narrative and numeric indicators of impairment implies that aquatic ecosystems are susceptible to a wide variety of stressors. For example, impairment of fish consumption as a designated use could be determined by an exceedance of the AWQC for toxic pollutants (i.e., violation of numeric water quality criteria) or through the comparison with one or more reference sites (i.e., failure to meet narrative biological criteria). This type of impairment also could be determined by a decrease in the DO concentration in the water body below target levels. Each of these indicators leads to the same finding that the water body is impaired; however, each indicator may be related to a different type of stressor and source. Therefore, a key to understanding impairments and, ultimately, to effective management of watersheds is to understand the stressors that cause impairments and the likely sources of those stressors. Specifically, distinguishing between the different stressors and sources that cause impairments will help identify those that are most amenable to control.

As shown in Table 3-1, stressors related to water body impairment may be organized into three major categories—physical, chemical, and biological. As discussed in Section 3.1.2, identifying/characterizing stressors is essential in developing a comprehensive understanding of the impairment of designated uses.

TABLE 3-1

Examples of Stressors and Sources that Can Cause Impairments

Stressor Category	Stressor Examples	Source Examples
Physical	Change in sediment substrate DO, temperature Physical or thermal injury to fish Flow/gradient changes	Destruction of riparian habitat Dam construction Cooling towers Water withdrawal
Chemical	Pesticides (atrazine) Metals, pH Nutrients, ammonia Polycyclic aromatic hydrocarbon (PAHs), phthalates Disinfection by-products Dioxins, mercury	Agricultural applications Stormwater runoff Animal feedlot operations Industrial discharges Wastewater treatment Stack emissions
Biological	Predation, competition Pathogens Overharvesting	Nonnative species introduction Combined sewer operations Commercial fishing pressure

3.1.2. Understanding Stressor Identification

In 2000, U.S. EPA published the *Stressor Identification Guidance Document* (hereafter *Guidance*) (U.S. EPA, 2000) to provide assistance to U.S. EPA regions, states, and tribes in their efforts to protect the biological integrity of the nation's waters. The document recognizes that, although bioassessments are useful for identifying biological impairments, they do not identify the causes of impairments. This shortcoming is due in large part to the complexity in linking biological effects with causes when multiple stressors (e.g., toxics, nutrient loads, habitat destruction) affect a water body. Thus, the *Guidance* bridges an important gap between identifying impairments and characterizing the causes (i.e., stressors) of those impairments (U.S. EPA, 2000). To provide the reader with a sense of how stressor identification supports the ERA process discussed in Section 3.1.3, this section presents a brief summary of how evidence is analyzed and how impairment causes are characterized (Chapters 3 and 4 of the *Guidance*).

3.1.2.1. *Analyzing the Evidence*

Once candidate causes of impairment are identified, the next step in the stressor identification process is to determine whether existing data are sufficient to determine a causal relationship between stressor and impairment. Data from studies of a particular water body, as well as from studies on other water bodies or from laboratories (e.g., effluent toxicity tests, biological surveys, habitat analyses), are all potentially useful, but site and laboratory data do not constitute evidence of causation. Investigators have to analyze these data to delineate associations between stressors and responses relevant to the site of interest. Chapter 3 of the *Guidance* includes detailed instructions for these analyses, including discussions on the following elements:

- associations between measurements of candidate causes and effects,
- use of effects data from elsewhere,
- measurements associated with causal mechanism, and
- associations of effects with mitigation or manipulation of causes.

This step in stressor identification feeds the development of stressor-response profiles in the ERA to establish, and possibly quantify, the relationship between stressors and adverse ecological effects.

3.1.2.2. *Characterizing Causes*

After the available evidence has been compiled and analyzed, the next step in the process is to characterize causes *and* state the level of confidence in that conclusion. Chapter 4 of the *Guidance* presents a systematic method for reaching a conclusion, consisting of two steps: (1) inferring causation and (2) summarizing probable cause and evaluating confidence. To characterize causation, U.S. EPA recommends an iterative process. This process begins with eliminating alternatives based on negative evidence, such as when the effects of concern occur upstream, as well as downstream, of the discharge of the stressor. The elimination step is followed by diagnoses that rely on positive evidence, such as the observation in affected organisms of symptoms known to be characteristic of a particular stressor. The process culminates in a strength of evidence analysis. Evaluating the strength of evidence involves a series of considerations, such as plausibility, specificity, analogy, and predictive performance, among other attributes pertinent to evidential discussions. Assuming that the iterative process identifies one or more sufficient causes of the impairment, the results of the characterization must be summarized and described with respect to uncertainties.

3.1.3. Understanding Ecological Risks

There is a substantial body of information available from U.S. EPA and other sources on ERA. In particular, U.S. EPA's *Guidelines for Ecological Risk Assessment* (U.S. EPA, 1998) provides a widely accepted framework for designing, implementing, and interpreting ERAs; and Bruins et al. (2005) discuss the application of ERA specifically to watershed management problems and presents a series of case studies. Consequently, the following discussion on ERA is intentionally brief and focuses on three elements: (1) defining assessment endpoints for aquatic ecosystems, (2) understanding key ERA concepts in building the conceptual model and the influence of stressor identification on that process, and (3) characterizing risks to aquatic ecosystems.

3.1.3.1. *Defining Assessment Endpoints for Aquatic Ecosystems*

Assessment endpoints are developed to characterize and represent the valued ecological characteristics identified in the management objectives. The process of defining these endpoints identifies the characteristics that are both ecologically relevant and susceptible to stressors, and it selects specific ecological entities and measurable attributes to embody those valued characteristics in the analysis. However, selecting assessment endpoints remains a challenging step. A recent U.S. EPA report (U.S. EPA, 2003) has developed a set of generic ecological assessment endpoints (GEAEs) that can be used as examples for ERA. In that document, the process of developing assessment endpoints is described in terms of five basic questions:

(1) What is susceptible to the stressor (stressor characteristics)?
(2) What is present and ecologically relevant (ecosystem/receptor characteristics)?
(3) What is relevant to the management goals (management goals)?
(4) What is of concern to stakeholders (input by interested parties)?
(5) What is supported by policy or precedent (GEAEs and policies/precedents)?

The document also identifies several specific examples of assessment endpoints that are grouped into four categories according to whether they characterize conditions at the level of organisms, populations, or ecosystems and communities, or whether they correspond to officially designated endpoints, such as critical habitats under the Endangered Species Act.

3.1.3.2. *Understanding Key Concepts in ERA Conceptual Model Development*

The framework for ERA consists of three phases: (1) problem formulation, (2) analysis, and (3) risk characterization. In the first phase, information is gathered to develop and evaluate preliminary theories about why ecological effects (or impairments) have occurred, or may occur, as a result of human actions. The conceptual model that emerges from that process depicts how the stressor is presumed to interact with the ecosystem. It provides both a written description and visual representation (diagram) of predicted relationships between ecological entities and the stressors to which they may be exposed (U.S. EPA, 1998). In developing the conceptual model, the diagram depicts exposure scenarios in which land-use or human activities are linked to specific stressors, and it shows the relationship between those stressors and the ecosystem processes and components that influence receptor responses (and, therefore, relate directly to impairment). Thus, as information from the stressor identification process is brought into the ERA, the conceptual models will evolve to reflect new data and analyses of the causes of water quality impairment. These improvements in the quality of the expanded conceptual models will reduce the overall uncertainty in the ERA and provide a more rigorous basis for decision-making.

One of the most important features of the conceptual model is its representation of a set of theories that describe predicted relationships among the source, stressor, exposure, and assessment endpoint response. Although these theories are sometimes referred to as "risk hypotheses" this term does *not* refer to a test for causality based on statistical inference. As discussed later, developing these risk theories is particularly important because they provide the basis for expanding the conceptual models (Section 3.3). These expanded models depict the impact of management options (e.g., protecting riparian buffer) on stressors; track these changes through ecosystem processes/components; and, ultimately, assess changes in both ecosystem services and regulatory compliance (e.g., attainment of designated uses). Thus, the conceptual model allows one to fully understand the risk theories that are being evaluated by selecting management option "A," and it allows one to identify the ecological responses that are expected under option "A." The risk theories illustrated in the conceptual model provide the framework to evaluate the functional relationships among management options, stressors, and responses within the context of decisions involving use attainment and antidegradation.

Any conceptual model that illustrates complex relationships among sources, stressors, exposure, and responses is, of course, subject to uncertainty. Indeed, conceptual model development may be one of the most important sources of uncertainty in risk assessment (U.S. EPA, 1998). Uncertainty arises from many sources, including a lack of knowledge about how the ecosystem is currently functioning (e.g., is it already in a vulnerable state?); inadequate data on the effects of a stressor on biological components of the ecosystem; and insufficient information on the interactions among different types of chemical, biological, and physical stressors. If important relationships between stressors and other model components are misrepresented (or missed entirely), the risk characterization may misrepresent actual risks. Because model simplification and knowledge gaps are the norm in conducting an ERA, it is particularly important that information developed during the stressor identification be used to reduce the sources of uncertainty or, at a minimum, to characterize the relative importance of key sources of uncertainty.

3.1.3.3. *Characterizing Risks to Aquatic Ecosystems*

The scientific components of the WQS used in an ERA primarily include the AWQC. The AWQC include (1) numeric limits for toxic contaminants and water quality metrics such as

DO; (2) nutrient criteria, which may establish target concentrations for nitrogen or phosphorous; and (3) biocriteria, which are numeric target values of multimetric indices such as the IBI and Invertebrate Community Index (ICI). These indices and their target values are often adjusted to fit regional conditions. They provide “what should be” benchmarks that represent unimpaired reference water bodies. Thus, the ecological risk characterization for aquatic systems typically compares modeled or measured conditions (e.g., pollutant concentrations, abundance and composition of invertebrate species) to reference benchmarks to determine whether the water body is in compliance with these standards. Because the numeric WQS tend to be point values for nationwide or regional use, the uncertainty in these limits is seldom explored; however, the uncertainty in exposure to pollutants released into aquatic systems is often examined using probabilistic modeling simulations.

With few exceptions, the practice of ERA tends to rely on consensus reference benchmarks (i.e., concentration thresholds) rather than on all of the information on the toxicity of a given pollutant. Thus, the emphasis of the risk characterization is on developing a qualitative discussion and, in some cases, a quantitative expression of the certainty that the WQS will or will not be exceeded. Unfortunately, this approach to characterizing risks to aquatic ecosystems addresses only some of the multiple stressors that affect the structure, function, and general “health” of the ecosystem. For instance, hydrological modification (e.g., water withdrawal, flow control), stream channel modification, removal of riparian vegetation, and introduction of nonnative species are not addressed in characterizing risks as part of the WQS. In addition, the potential effects associated with exposure to multiple stressors (e.g., increased macrophyte growth and toxics loadings) and the effects of chemical stressors for which no WQS have been developed are not considered. Although mechanistic models such as AQUATOX Version 2.0 (U.S. EPA, 2004) significantly expand our ability to evaluate effects from multiple stressors, the focus of risk characterization to aquatic ecosystems tends to be limited to the probability of meeting each of the WQS relevant to a particular body of water.

3.2. UNDERSTANDING ECOSYSTEM SERVICES AND DESIGNATED USES

For decision-makers to understand the broader ramifications of alternative approaches for attaining WQS, it often is necessary to look beyond the financial and economic impacts and changes in designated use attainment discussed in Chapter 2 and the ecological endpoints discussed above in Section 3.1. It requires a framework that helps decision-makers better understand how humans interact with and derive services from the affected ecological systems and how these services are related to WQS management options and designated uses. To establish this type of framework, the following sections define and describe aquatic ecosystem services and their relationship to designated uses.

3.2.1. Aquatic Ecosystem Services

The concept of ecosystem services is fundamental for evaluating how humans are supported by ecological systems and how their well-being is affected by changes in these systems (see, for example, Daily [1997] or Millennium Ecosystem Assessment [2005]).[1] This report adopts the following definition provided by U.S. EPA (2006):

> **Ecosystem services** are outputs of ecological functions or processes that directly or indirectly contribute to social welfare or have the potential to do so in the future. Some may be bought and sold, but most are not marketed.

For the purpose of setting and evaluating WQS, the concept of *aquatic ecosystem services* is particularly important. These are the services specifically derived from surface water resources and their connected ecosystems. They are also the ecosystem services primarily affected by alternative water quality management options.

Figure 3-2 illustrates the link between aquatic ecosystems and the services derived from these systems. It describes in simplified terms the primary components and processes of a functioning aquatic ecosystem.[2] They include the physical habitat (e.g., stream bed characteristics and the flow of water through the system) and the biological components of the habitat (e.g., fish populations and species diversity), and the chemical, biological, and hydrological processes that occur within the ecosystem. These components and processes directly influence and are also influenced by the level of water quality (e.g., DO content and pH levels) in the system.

[1] The Millennium Ecosystem Assessment supports decision-making related to the effects of ecosystem change on humans. It focuses on ecosystem services and human well-being. It also examines local, national, and global options for conserving these services. Although this U.S. EPA report was not written to correspond with the Millennium Ecosystem Assessment, both are fairly consistent in definitions and framework.

[2] Although Figure 3-2 represents stream processes, it could depict other aquatic ecosystems.

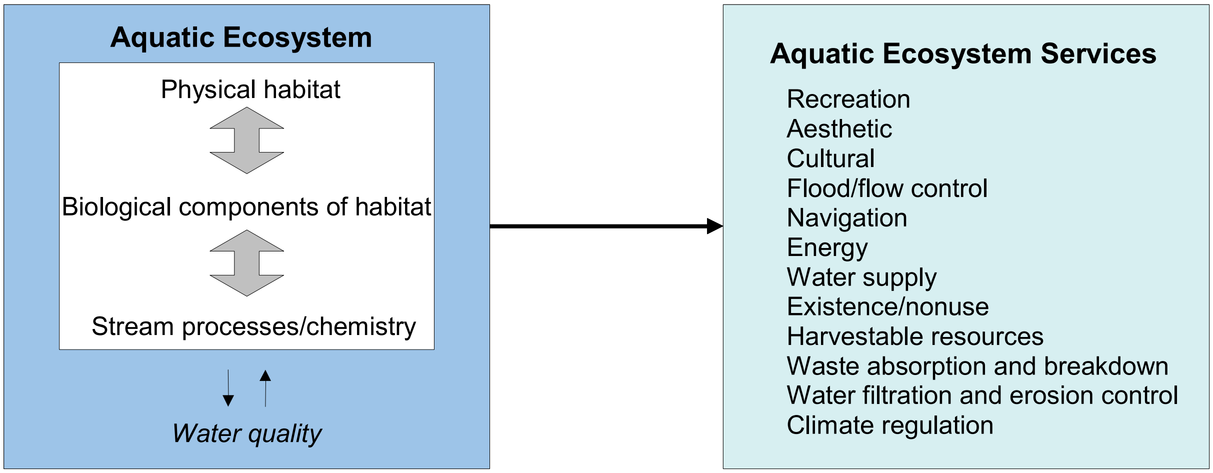


FIGURE 3-2

Services Derived from Aquatic Ecosystems

Figure 3-2 shows that the interrelated features of an aquatic ecosystem are together capable of providing a wide range of ecosystem services to humans. These services are in many cases derived from specific human uses of surface water resources and their associated aquatic ecosystems. The uses include activities that are primarily commercial, such as commercial fishing, navigation, energy production, and agriculture (e.g., through crop irrigation). They also include “nonmarket” activities that are unrelated or only indirectly related to commercial activities, such as water-based recreation, subsistence fishing, and household water use. Other services provided by aquatic ecosystems relate to or support a wide variety of human uses. For example, flood control services protect commercial and residential properties as well as water-based recreational facilities. The Millennium Ecosystem Assessment (2005) describes some of these as supporting services which are used to support or produce other ecosystem services. Nutrient cycling is another example that supports and affects the condition of other ecosystem services. Aesthetic services from aquatic ecosystems (e.g., through appreciation of their natural beauty) enhance recreational, residential, and many other uses of water resources.

Only one of the ecosystem service categories—existence/nonuse—is, by definition, unrelated to any specific human uses of water resources. The argument for including existence/nonuse as a distinct category of ecosystem service is that individuals can gain satisfaction and fulfillment simply from the knowledge that an ecosystem (particularly a well-functioning and healthy one) exists. These services can arise for several reasons, including

- individuals value the ecosystem intrinsically,
- they value the satisfaction others get from using the resource (altruistic value),[3]
- they value preserving the resource for future generations (bequest/preservation value), and/or
- they gain satisfaction from a sense of environmental stewardship.

Table 3-2 provides decision-makers with a richer characterization of the range, type, and measures of aquatic ecosystem services that may be affected by alternative water quality management options. It is intended to assist decision-makers in identifying, comparing, and

[3] In certain cases, altruism may not be a valid motive for existence value (see McConnell, 1997).

TABLE 3-2

Aquatic Ecosystem Services: Classification and Description of Services Supported by Healthy Aquatic Ecosystems

Service Category	Service Subcategory	Characteristics Related to the Service	Example Measures of Characteristics	Examples of Language Used to Describe the Service[a]	Location and Citation for Language Used
Recreational Services		Water quality • Clarity • Smell • Taste • Toxic pollutants • Visual impairments • Indicators of healthy ecosystem	• Visual (e.g., "Secchi") depth • Reported odors • Reported unpleasant tastes • Measurable pollutant concentrations • Presence of foam, oil scum, algal blooms • pH level, DO content	• No foam, clarity, purity, color, no odor, no bacteria, not so much algae • Odor • Floating objects, foam, algae, discoloration, cloudiness, oil scum, domestic sewage, weeds, odor, taste • Would not harm someone who happened to fall into it for a short time while boating or sailing	• Clear Lake, IA (Downing et al., 2001) • Connecticut River, New England (Mullens and Bristow, 2003) • Lakes in Canada (Parkes, 1973) • Water bodies in the U.S. (Carson and Mitchell, 1993)
		Site characteristics • Recreational facilities • Congestion • Landscape aesthetics • Location • Uniqueness	• Number of boat launches, piers, beach/shore access points, lifeguards, hiking paths, camping sites, picnic facilities, wildlife viewing blinds, and/or hunting blinds • Number of people or boats in view • Number of visible manmade structures • Presence of unique vistas • Proximity to population centers • Proximity to comparable sites	• People or boats one expects to see • Number of other groups (canoeing) encountered per day • Take guests for ride, picnic, celebrate events • Number of people seen at the hunting site, travel method, distance of hunting site from home	• Susquehanna River Basin, PA, and James River Basin, VA (Heberling, 2000) • Three Ontario parks, Canada (Boxall et al., 2003) • Mangrove wetlands of Yucatan, Mexico (Kaplowitz, 2000) • Northwest Saskatchewan, Canada (Haener et al., 2001)

TABLE 3-2 cont.

Service Category	Service Subcategory	Characteristics Related to the Service	Example Measures of Characteristics	Examples of Language Used to Describe the Service[a]	Location and Citation for Language Used
Recreational Services (continued)	Recreational fishing	Presence/abundance of target species	• Catch rate per unit effort • Size/number/health of adult fish	• Fish population • Population of salmon in river • Number and size of fish caught • Catch rate (actual, potential, expected)	• John Day River, OR (Johnson and Adams, 1989) • Elwha River, WA (Loomis, 1996) • Idaho (Donnelly et al., 1985) • San Francisco Bay, CA (Huppert, 1989); Cache la Poudre River, CO (Daubert and Young, 1981); Tar-Pamlico River, NC (Whitehead and Groothius, 1992)
		Healthy aquatic community	• Age structure of population • Diversity of species	• Presence of game fish and rough fish	• Water bodies in the U.S. (Carson and Mitchell, 1993); Iowa and Illinois river basins (Lant and Roberts, 1990)
		Safety of fish for human consumption	• Fish consumption advisories (presence and type) • Pollutant concentrations in fish tissue	• Sensory cues (e.g., smell, observations of dead or dying fish, bad taste) • Aware of fish consumption advisories or health advisories for sport-fish caught in certain waters	• Michigan and Kansas (Cable and Udd, 1990) • New York State (Connelly et al., 1992); Great Lakes waters (Connelly and Knuth, 1993)

TABLE 3-2 cont.					
Service Category	Service Subcategory	Characteristics Related to the Service	Example Measures of Characteristics	Examples of Language Used to Describe the Service[a]	Location and Citation for Language Used
Recreational Services (continued)	Recreational fishing (continued)	Habitat quality • Flow/hydrology • Water quantity • Stream bed quality • Spawning habitat	• Volume per unit time after rain events • Baseline volume of water • Sediment substrate type and size • Presence of pools/rooted vegetation • Mature vegetation in buffer area	• Development threatens wildlife • Variety of vegetation, vegetation shade to keep water cool for fish and reduce algae growth, stream corridors important for animal migration	• Grand River Watershed, Canada (Brox et al., 1996) • South Platte River, CO (Loomis et al., 2000)
	Boating	Habitat quality • Flow/hydrology • Water quantity	• Volume per unit time after rain events • Baseline volume of water	• Development threatens fish, waterfowl, songbirds, and other creatures in marshes and woodlands	• Grand River Watershed, Canada (Brox et al., 1996)
	Swimming	Safety	• Presence/type of water quality advisories • Frequency of water quality advisories • Frequency of water quality-related beach closures • Incidence of skin/eye/ear irritation	• Irritation (skin, eyes, ears)	• Lakes in Canada (Parkes, 1973)
	Hiking	Habitat quality	• Health and maturity of riparian vegetation	• Development threatens fish, waterfowl, songbirds, and other creatures in marshes and woodlands	• Grand River Watershed, Canada (Brox et al., 1996)
				• Variety of vegetation, shelter and areas for nesting and roosting, vegetation shade to keep water cool for fish and reduce algae growth, stream corridors important for animal migration	• South Platte River, CO (Loomis et al., 2000)

TABLE 3-2 cont.					
Service Category	Service Subcategory	Characteristics Related to the Service	Example Measures of Characteristics	Examples of Language Used to Describe the Service[a]	Location and Citation for Language Used
Recreational Services (continued)	Wildlife viewing	Presence/abundance of target species	• Population of target species, in particular wild, rare, symbolic, and charismatic species	• Populations and sightings of endangered species	• California coast (Loomis and Larson, 1994)
		Habitat quality	• Population and health of riparian and aquatic vegetation • Presence/quality/extent of habitat for species of interest	• Development threatens fish, waterfowl, songbirds, and other creatures in marshes and woodlands • Variety of vegetation, shelter and areas for nesting and roosting, vegetation shade to keep water cool for fish and reduce algae growth, stream corridors important for animal migration	• Grand River Watershed, Canada (Brox et al., 1996) • South Platte River, CO (Loomis et al., 2000)
	Hunting	Presence/abundance of target species	• Population of target species • Bag rate per unit effort	• Signs of moose seen daily	• Northwest Saskatchewan, Canada (Haener et al., 2001)
		Habitat quality	• Presence/quality/extent of habitat for target species	• Development threatens fish, waterfowl, songbirds, and other creatures in marshes and woodlands • How long it has been since the site was harvested • Shelter and areas for nesting and roosting, stream corridors important for animal migration	• Grand River Watershed, Canada (Brox et al., 1996) • Northwest Saskatchewan, Canada (Haener et al., 2001) • South Platte River, CO (Loomis et al., 2000)

TABLE 3-2 cont.					
Service Category	Service Subcategory	Characteristics Related to the Service	Example Measures of Characteristics	Examples of Language Used to Describe the Service[a]	Location and Citation for Language Used
Aesthetic Services		Water quality • Clarity • Smell • Visual impairments	• Visual (e.g., "Secchi") depth • Reported odors • Visible foam, oil scum, algal blooms	• No foam, clarity, purity, color, no odor, no bacteria, not so much algae • Odor • Floating objects, foam, algae, discoloration, cloudiness, oil scum, domestic sewage, weeds, odor	• Clear Lake, IA (Downing et al., 2001) • Connecticut River, New England (Mullens and Bristow, 2003) • Lakes in Canada (Parkes, 1973)
		Habitat quality	• Presence/quality/extent of habitat	• Variety of vegetation, shelter and areas for nesting and roosting, vegetation shade to keep water cool for fish and reduce algae growth, stream corridors important for animal migration	• South Platte River, CO (Loomis et al., 2000)
		Site characteristics • Landscape aesthetics • Location • Uniqueness	• Number of visible manmade structures • Presence of unique vistas • Proximity to population centers • Proximity to comparable sites	• Appearance • Beauty (beautiful, pretty, views), take guests for ride, picnic, celebrate events • Percentage difference in rental value/sale price for: unit facing water one facing away from water in the same building, different types of water bodies (river vs. canal), proximity to water body, and proximity to dock on canal	• Grand River Watershed, Canada (Brox et al., 1996) • Mangrove wetlands of Yucatan, Mexico (Kaplowitz, 2000) • Mercy Basin, England (Wood and Handley, 1999)

TABLE 3-2 cont.					
Service Category	Service Subcategory	Characteristics Related to the Service	Example Measures of Characteristics	Examples of Language Used to Describe the Service[a]	Location and Citation for Language Used
Cultural Services		Presence and significance of cultural sites	• Number of cultural sites • Number of archeological sites • Number of religious sites	• Protection of historic shipwrecks from treasure hunters	• Eastern North Carolina (Whitehead and Finney, 2003)
		Access to cultural sites	• Absence of barriers to culturally significant uses of resources • Absence of barriers to visit or view sites	• Distance of hunting site from home, number of people seen at the hunting site, signs of moose seen daily, travel method, how long it has been since the site was harvested	• Northwest Saskatchewan, Canada (Haener et al., 2001)
Flood/Flow Control Services		Property protection	• Reduced frequency/extent of flood damage • Avoided costs of flood damage	• Flood protection	• Wetlands in New England (Stevens et al., 1995) • Roanoke, VA (Shabman and Stephenson, 1996)
		Safety	• Reduced risk of death or injury due to floodwaters	• Percentage chance of flood waters entering the first floor or basement	
Navigation Services		Capacity for navigation (depends on depth and flow)	• Maximum volume/weight of shipped goods per unit time • Maximum number of persons per unit time • Cost of shipping or transportation • Quantity/volume of goods shipped • Quantity of trips • Price of shipped goods • Producer surplus[b] – Returns/profits from commercial transport – Returns/profits to uses of shipped goods • Consumer surplus[c] – Availability of cheaper or better quality transport		

TABLE 3-2 cont.					
Service Category	Service Subcategory	Characteristics Related to the Service	Example Measures of Characteristics	Examples of Language Used to Describe the Service[a]	Location and Citation for Language Used
Energy Services		Water flow for hydroelectricity generation	• Cost of electricity production and delivery • kWh of electricity produced and consumed • Producer surplus[b] – Returns/profits for commercial energy suppliers – Returns/profits for commercial users of electricity • Consumer surplus[c] – Availability of cheaper electricity and other goods	• Presence (or absence) of a hydroelectric power station in a national park	• Riverside wetlands in "Donau-Auen" national park, Austria (Kosz, 1996)
Water Supply Services	Industrial water supply • Cooling water • Other industrial uses	Water flow/quality for industrial uses	• Costs of water for industrial uses • Costs of treating water for industrial uses • Quantity of water used for industrial uses • Producer surplus[b] – Returns/profits for industrial producers • Consumer surplus[c] • Availability of cheaper goods		

TABLE 3-2 cont.

Service Category	Service Subcategory	Characteristics Related to the Service	Example Measures of Characteristics	Examples of Language Used to Describe the Service[a]	Location and Citation for Language Used
Water Supply Services (continued)	Agricultural water supply • Irrigation • Other agri-cultural uses	Water flow/quality for agricultural uses	• Costs of water for agricultural uses • Costs of treating water for agricultural uses • Quantity of water used for agricultural uses • Producer surplus[b] – Returns/profits for agricultural producers – Returns/profits for users of agricultural goods • Consumer surplus[c] • Availability of cheaper agricultural and other goods		
	Household water supply • Drinking water • Other house-hold uses	Water supply for household users	• Costs of water for household uses • Costs of treating water for household uses • Quantity of water used for household uses • Producer surplus[b] – Returns/profits to commercial water utilities • Consumer surplus[c] • Availability of cheaper household water	• Million gallons of water daily (mgd) extracted, reduction in the level of water in river	• Río Mameyes and Río Fajardo, Puerto Rico (González-Cabán and Loomis, 1997)

TABLE 3-2 cont.					
Service Category	Service Subcategory	Characteristics Related to the Service	Example Measures of Characteristics	Examples of Language Used to Describe the Service[a]	Location and Citation for Language Used
Water Supply Services (continued)		Water quality • Clarity • Odor • Taste • Health/safety	• Cloudiness • Reported odors • Reported tastes • Concentrations of harmful pollutants • Presence of drinking water advisories	• No foam, clarity, purity, color, no odor, no bacteria, not so much algae • Odor • Discoloration, cloudiness, odor, irritation (skin, eyes, ears), taste • Bad water quality (color and bad smell) • Appearance, odor • Taste, odor, color, skin/eye irritation	• Clear Lake, IA (Downing et al., 2001) • Connecticut River, New England (Mullens and Bristow, 2003) • Lakes in Canada (Parkes, 1973) • Mexico City, Mexico (Soto Montes de Oca et al., 2003) • Grand River Watershed, Canada (Brox et al., 1996) • Orlando, FL (DeLorme et al., 2003)
		Characteristics of water distribution • Reliability • Capacity	• Number of water outages per unit time • Number of hours of service per unit time	• Shortages, low water pressure • Avoidance of water restrictions, reliability improvement in water supply system • Quality of city water service and reliability of water system, shortages, restrictions on water use, cost	• Mexico City, Mexico (Soto Montes de Oca et al., 2003) • Seven Texas cities (Griffin and Mjelde, 2000) • Boulder, Longmont, and Aurora, CO (Howe et al., 1994)
	Groundwater recharge	Water flow	• Base flow • Groundwater levels	• Improve aquifer recharge rate and ensure a stable supply of groundwater	• Cagayan de Oro, Phillipines (Palanca-Tan and Bautista, 2003)

TABLE 3-2 cont.					
Service Category	Service Subcategory	Characteristics Related to the Service	Example Measures of Characteristics	Examples of Language Used to Describe the Service[a]	Location and Citation for Language Used
Existence/ Nonuse Services[d]		Biodiversity • Complexity of community and redundancy of species • Sustainability of rare, threatened, or endangered species	• Number of different species present in ecosystem • Number/size/health of rare, threatened, or endangered species • Probability of long-term survival of key species • Preservation of genetic resources	• Containing rare species of plants that provide ecosystem stability and genetic diversity • Populations and sightings of endangered species • Population of salmon in river	• Wetlands in New England (Stevens et al., 1995) • California coast (Loomis and Larson, 1994) • Elwha River, WA (Loomis, 1996)
		Water quality • Clarity • Smell • Toxic pollutants • Visual impairments • Indicators of healthy ecosystem	• Visual (e.g., "Secchi") depth • Reported odors • Measurable pollutant concentrations • Visible foam, oil scum, algal blooms • pH level, DO content		
		Habitat quality • Water quantity • Spawning habitat • Nutrient management	• Baseline volume of water • Presence of pools/rooted vegetation • Presence/quality/extent of habitat for charismatic species • Mature vegetation in buffer area • Total nitrogen and phosphorous concentrations	• Instream flows (presence of water in rivers and streams as well as support of wildlife, vegetation, and habitat) • Variety of vegetation, shelter and areas for nesting and roosting, vegetation shade to keep water cool for fish and reduce algae growth, stream corridors important for animal migration	• New Mexico (Berrens et al., 2000) • South Platte River, CO (Loomis et al., 2000)

TABLE 3-2 cont.

Service Category	Service Subcategory	Characteristics Related to the Service	Example Measures of Characteristics	Examples of Language Used to Describe the Service[a]	Location and Citation for Language Used
Harvestable Resources	Commercial harvesting • Fishing • Harvest-ing of raw materials	Presence/abundance of target species	• Capital and operating costs for fishermen • Cost of fishing trips • Wholesale and retail price of fish • Quantity of fish caught • Quantity of fish consumed in wholesale or retail market • Producer surplus[b] – Costs of production (catch rate per unit effort) – Returns/profits to commercial fishers • Consumer surplus[c] – Availability of cheaper commercial fish		
		Safety of harvest for human consumption	• Fish consumption advisories (presence and type) • Fish tissue pollutant concentrations		
		Presence/abundance of materials	• Cost of harvest • Wholesale and retail price of materials • Quantity of material harvested • Quantity of materials consumed in wholesale or retail market • Producer surplus[b] – Returns/profits to commercial harvesters of raw materials – Returns/profits to users of harvested materials • Consumer surplus[c] – Availability of cheaper material	• Mining development (impact of resulting pollution would eliminate potential for recreational use in waterways)	• South Platte River Basin, CO (Greenley et al., 1981)

TABLE 3-2 cont.					
Service Category	Service Subcategory	Characteristics Related to the Service	Example Measures of Characteristics	Examples of Language Used to Describe the Service[a]	Location and Citation for Language Used
Harvestable Resources (continued)	Subsistence harvesting • Fishing • Hunting	Presence/abundance of target species	• Population of target species • Catch rate per unit effort • Size/health of fish	• Sport fishing as a source of food (anglers may not consider themselves to be subsistence fishing)	• Buffalo, NY (Beehler et al., 2003)
		Safety of harvest for human consumption	• Fish consumption advisories (presence and type) • Fish tissue pollutant concentrations		
Waste Absorption and Breakdown		Assimilative capacity	• Avoided alternative waste disposal costs	• Adequate river flows to dilute fertilizer and pesticides from runoff, wastewater discharges, and pollutants in stormwater, insures the river is not toxic to fish and safe for water-based recreation	• South Platte River, CO (Loomis et al., 2000)
Water Filtration and Erosion Control		Riparian and wetland vegetation	• Presence and extent of riparian buffer • Presence and extent of wetland vegetation		
Climate Regulation		Capacity for carbon storage	• Presence and extent of vegetation		
		Microhabitat features	• Humidity levels		

[a]Sources of these terms include actual questionnaires, survey descriptions, and summaries of focus group discussions.
[b]Measure of seller's well-being.
[c]Measure of buyer's well-being.
[d]Although not shown here, service subcategories for existence/nonuse services could include the existence of all the other service categories. For example, someone may value cultural services they would never use.

evaluating the relevant gains and losses between affected services.[4] The table also presents terminology that may be more adequate for communicating changes to communities. Table 3-2 highlights how ecosystem services are connected to water quality or water quantity characteristics. It begins to link changes in ecosystems to measurements in ecosystem services in order to understand the gains and losses perceived by communities.

The first column of Table 3-2 includes the main categories of aquatic ecosystem services, which correspond with those shown in Figure 3-2. The second column divides 3 of the 12 main categories into a total of 12 subcategories. For example, recreational services are divided into six subcategories of recreational activities—fishing, boating, swimming, hiking, wildlife viewing, and hunting. The third column identifies key characteristics of the water resource or service category that affect the level and quality of the services provided. For example, water quality, habitat quality, health/safety, water flow, and landscape aesthetics are included in multiple subcategories. Importantly, water quality does not play a significant role in all of the service categories. Although recreational, aesthetic, and existence/nonuse services are undoubtedly enhanced by improvements in water quality, others such as energy and navigation services are more strongly influenced by water flow and other physical characteristics of the water resource. However, even ecosystem services that are not directly affected by water quality may need to be considered in evaluating WQS management options. For example, one option for attaining boatable/fishable water quality conditions on a river segment might be to remove a dam, but this removal could have a negative impact on energy and flood control services. In this case, the WQS management decision requires consideration of the gains and losses between different types of aquatic ecosystem services, some of which involve water quality and others that do not.

The fourth column in Table 3-2 lists examples of measures that correspond to the characteristics in the previous column. By measuring characteristics of water resources that relate to specific services, they also can be thought of and used as indicators of the level or quality of services provided by aquatic ecosystems. The measures listed in this column do not provide an exhaustive list of the relevant and possible measures for each service. Rather they provide key examples of measures to serve as a reference and starting points for analysts and

[4] As discussed in Chapter 1, the examination of the relevant gains and losses is in addition to the analyses described in the existing guidance to determine if the communities would prefer the new situation.

decision-makers. These measures can be adapted or supplemented as necessary to evaluate and compare changes to specific ecosystem services.

The fifth column presents examples of how aquatic ecosystem services have been described to (e.g., in surveys) or by the general public. These descriptors are generally less technical than those listed in the previous column, and they are meant to serve a different purpose. Whereas the measures listed in column four are intended to provide analysts with tools for quantifying and evaluating changes in ecosystem services, the descriptors listed in column five provide terms that may be more appropriate for communicating these changes to the general public. These terms were drawn from the research literature exploring values, attitudes, and perceptions regarding water quality and aquatic ecosystem services. Locations and references for each of the relevant studies are provided in the last column of Table 3-2.

3.2.2. Relating Aquatic Ecosystem Services to Designated Uses

Given the well-defined and critical role of designated use attainment in WQS decision-making and the potential role of aquatic ecosystem services in evaluating communities' preferences, it is important to consider how they relate to one another. In essence, they represent two distinct but related ways of characterizing how well conditions in a water resource support human well-being. One important difference is that use attainment is a dichotomous indicator of conditions in the water body (i.e., for each designated use category, either the designated use is attained or it is not), whereas services are best represented by more continuous measures. Consequently, when water quality management decisions result in changes to designated uses, they also are likely to affect the types and levels of ecosystem services that are provided by the water resource.

However, changes in designated use attainment are not a necessary condition for changes in aquatic ecosystem services. As Figure 3-2 implies, *any* alteration to the structure or functioning of the aquatic ecosystem will have potential implications for the types and levels of services that are derived from the system. Therefore, decisions about changing designated uses could effect multiple ecosystem services, but they will not likely be identified by the analyses described in the existing guidance.

To illustrate the relationship between designated use attainment and aquatic ecosystem services, Table 3-3 provides a matrix linking the main designated use categories with the main

TABLE 3-3

Aquatic Ecosystem Services

Aquatic Ecosystem Services		Example of Designated Use Category										
Main Category	Subcategory	Primary Contact Recreation (Safe to Swim)	Secondary Contact Recreation (Safe to Fish, Boat)	Ag Water Supply (Irrigation and Livestock)	Industrial Water Supply	Hydro-power Generation	Public Water Supply	Aesthetics (Visibility, Odor)	Fish Consump-tion (Safe to Eat Fish)	Aquatic Life (Cold and Warm Water)	Shellfish Harvest-ing Waters	Naviga-tion
Recreation												
	Fishing		●					○	●	●	●	
	Boating		●					○		○		
	Swimming	●						○				
	Hiking							○		○		
	Wildlife viewing							○		○		
	Hunting							○		○		
Aesthetic								●		○		
Cultural								○		○		
Flood/Flow Control												
Navigation												●
Energy						●						
Water Supply												
	Industrial				●							
	Agricultural			●								
	Household						●					
	Groundwater recharge											

●—Attainment of this designated use category directly supports/enhances this aquatic ecosystem service.
○—Attainment of this designated use category indirectly or partially supports/enhances this aquatic ecosystem service.

TABLE 3-3 cont.

Aquatic Ecosystem Services		Example of Designated Use Category										
Main Category	Subcategory	Primary Contact Recreation (Safe to Swim)	Secondary Contact Recreation (Safe to Fish, Boat)	Ag Water Supply (Irrigation and Livestock)	Industrial Water Supply	Hydro-power Generation	Public Water Supply	Aesthetics (Visibility, Odor)	Fish Consump-tion (Safe to Eat Fish)	Aquatic Life (Cold and Warm Water)	Shellfish Harvest-ing Waters	Naviga-tion
Existence/ Nonuse										●	●	
Harvestable Resources												
	Commercial harvesting		●						●	●	●	
	Subsistence harvesting		●						●	●	●	
Waste Absorption and Breakdown												
Water Filtration and Erosion Control												
Climate Regulation												

●—Attainment of this designated use category directly supports/enhances this aquatic ecosystem service.
○—Attainment of this designated use category indirectly or partially supports/enhances this aquatic ecosystem service.

aquatic ecosystem service categories. Although there are several closely corresponding categories, particularly for aquatic ecosystem services derived from specific uses of water (e.g., recreation, navigation, energy, water supply and harvestable resources), the categories do not all correspond one to one. In the matrix, the dark circles represent categories for which there is a direct correspondence between designated uses and services. For example, if a water body goes from nonattainment to attainment of the primary contact recreation use designation, this implies that the potential swimming services from the water body are directly enhanced.[5] The open circles represent categories for which a less direct correspondence is expected. For example, attainment of aquatic life and aesthetic standards in a water body will most likely but not necessarily enhance most recreational services from the water body.[6] It is important to note that, even for matched categories, nonattainment of a designated use does not necessarily mean that the corresponding services are zero. For example, nonattainment of the fish consumption designated use does not necessarily imply that the water body fails to provide any fishing services, but it does imply that those services are restricted. Similarly, attainment of a designated use category does not necessarily imply that the corresponding services are positive (see Footnote 5). The links between ecosystem services and designated uses are further described in the following section through expanded flow diagrams and case study examples of WQS decisions.

3.3. ASSESSMENT OF SOCIOECONOMIC ENDPOINTS AFFECTED BY USE ATTAINMENT DECISIONS

As discussed in Chapter 2, U.S. EPA's (1995) *Interim Economic Guidance* provides decision-makers and analysts with specific recommendations for estimating the financial impacts on private- and public-sector entities and the economic impacts on the community. Although these impacts are undoubtedly important endpoints for decision-makers to consider, the overall socioeconomic impacts associated with setting or modifying WQS are potentially much broader.

[5] Services are only "potentially" enhanced in these cases because attainment of a designated use does not necessarily imply that the use will take place at the water body; rather, it implies that the water body becomes more suitable for the use. For example, a water body may not be used in practice for swimming (e.g., due to difficulties with access to the water body) even if its water quality is suitable for swimming.

[6] We do not attempt to present all of the ecosystem services protected by the designated uses. For example, attaining the criteria established for public water supply may, in many but not all instances, enhance aesthetics and recreational services. The opposite could be true as well. A human activity that prevents the attainment may reduce more ecosystem services than identified in Table 3-3. These ancillary benefits or costs are important and should be examined on a case-by-case basis.

As described above, a more comprehensive view of the relevant impacts and trade-offs can be achieved by considering how ecosystem services are affected by alternative management options.

Any changes in human well-being (i.e., "human welfare gains or losses") resulting from WQS changes should be interpreted as relevant socioeconomic endpoints. Even in situations where it is not feasible to conduct a detailed, quantitative BCA, important insights can be gained by identifying and considering the full range of socioeconomic endpoints affected by changes in ecosystem services.

Changes to aquatic ecosystem services can affect human well-being in a variety of ways. Some of these effects will have direct monetary or market implications for individuals. For example, several services provided by water resources, such as commercial fishing, energy supply, and agricultural water supply, directly support market activities. As a result, changes in these services can affect both producers and consumers by changing the costs of production, prices, incomes, and employment related to these activities. These types of services and human welfare effects are illustrated, for example, in the case studies described in Section 3.4. For example, in Case Study 3, an intermittent stream ecosystem initially supports livestock and agricultural production, but with the management options in place, these services are curtailed. As a result, the farmer loses some of the profit he would have earned by selling his products on the market. Consumers of his products may be affected negatively. These market-related effects (referred to in the case study as changes in "market surplus") represent potentially important socioeconomic endpoints. In other cases, the costs of management options are not borne through market interactions, but rather through charges for public services (e.g., taxes, fees). In these cases (e.g., Case Study 1 below), the human welfare effects can be described as reductions in disposable income, disposable income, or the amount of money available for spending or saving net income taxes.

Both market surplus and disposable income changes can be addressed at least partially using methods outlined in the *Interim Economic Guidance* developed by U.S. EPA (1995). However, some aquatic ecosystem services have less direct but equally relevant monetary or market implications. For example, flood control services help prevent financial losses associated with property damage, and aesthetic services for near-shore residents are reflected in housing prices and property values. Therefore, changes to these services also can have impacts on prices, incomes, and employment (in these cases, mostly related to property markets and ownership). These socioeconomic endpoints also deserve consideration. In Case Study 4 below, these endpoints are included when considering the effects of allowing a mall development to occur. Possible damages to the wetland could result in more flooding and sedimentation downstream, which could, among other things, result in property value losses for downstream residents.

Other aquatic ecosystem services have little or no connection to markets or incomes; nevertheless, they still are valued by individuals and contribute to their well-being. Recreational services are a prime example. If, for instance, services from recreational fishing, boating, swimming, or other activities are affected by changes in water quality, these changes will not necessarily affect prices, incomes, or employment in any market. However, the absence of a direct monetary effect on individuals does not imply that there is no socioeconomic effect. In these cases, the relevant endpoint is the change in enjoyment individuals derive from their recreational activities. In all of the case studies, reducing the effects of stressors on aquatic ecosystems is shown to enhance recreational services and provide more value to recreational users of the resources.

Several other categories of ecosystem services have similar “nonmarket” characteristics. For example, in many cases, changes to aesthetic services or changes to services derived from cultural and subsistence activities will not have observable effects on prices or incomes. Again, despite the lack of a direct monetary impact, the change in individuals’ enjoyment of these activities represents a potentially important socioeconomic endpoint to be considered.

One category of ecosystem services is unique because it is not derived from any specific use or market related to the aquatic resource—nonuse/existence services. The effects of these services on human well-being are less tangible than other services and certainly more difficult to measure, but they may nonetheless be significant. As discussed in Section 3.2, the argument for considering these services is that individuals may well value protecting the existence and quality of natural resources that they never expect to use in any way. The motivations for these values may be altruistic (protecting the resource for other users and future generations), or they may be derived from a sense of stewardship or inherent responsibility for protecting the resource. These values are likely to be particularly strong for aquatic resources that are unique, threatened, or endangered. Regardless of the motivation for nonuse values, they represent another potentially important socioeconomic endpoint to consider as part of setting or modifying WQS, and for this reason they are included as potential human welfare gains in all five of the case study examples discussed in the next section.

3.4. MAPPING THE WATER QUALITY MANAGEMENT PROBLEM: DEVELOPING CONCEPTUAL MODELS

Conceptual models expressed as flow diagrams are particularly useful tools for representing relationships within and between ecological and human systems. As discussed in Sections 3.1 and 3.2 above, these diagrams play an integral role in stressor identification and in the problem formulation stage of ERA by illustrating relationships between sources, stressors, ecological entities, and their responses to the stressors. They can be used to illustrate the links between aquatic ecosystems and the services derived from them. This section presents conceptual models that expand Figure 3-2 to evaluate the broader societal implications and gains and losses associated with setting or modifying WQS. Their purpose is to illustrate how to lay out the problem and identify important trade-offs that need to be quantified or measured. The evaluation methods will be discussed in Chapter 4.

The section begins by presenting these expanded conceptual models in general terms. Second, several main steps are described for applying the general framework and developing conceptual diagrams that depict specific WQS conditions. Third, the diagrams are applied and illustrated through five case study WQS examples. The expanded models include the interconnections between sources, stressors, ecosystem components and processes, and ecological assessment endpoints, and they extend these links to include effects on ecosystem services and related socioeconomic impacts. In addition, they include linkages to management alternatives by showing how these alternatives alter inputs, relationships, ecosystem services, human welfare effects, and designated use attainment.

3.4.1. General Framework for the Expanded Conceptual Models

Figure 3-2, which illustrates the idea that ecosystem services are derived from the ecosystem components and processes, is the foundation for the expanded conceptual models. Building directly on Figure 3-2, Figure 3-3 shows that land uses and other sources of stress are capable of introducing stressors to aquatic ecosystems. These stressors disrupt the normal functioning of the ecosystem, which can cause reductions in water quality and can impair the ecosystem's ability to provide key services. However, as shown in Figure 3-3, these same

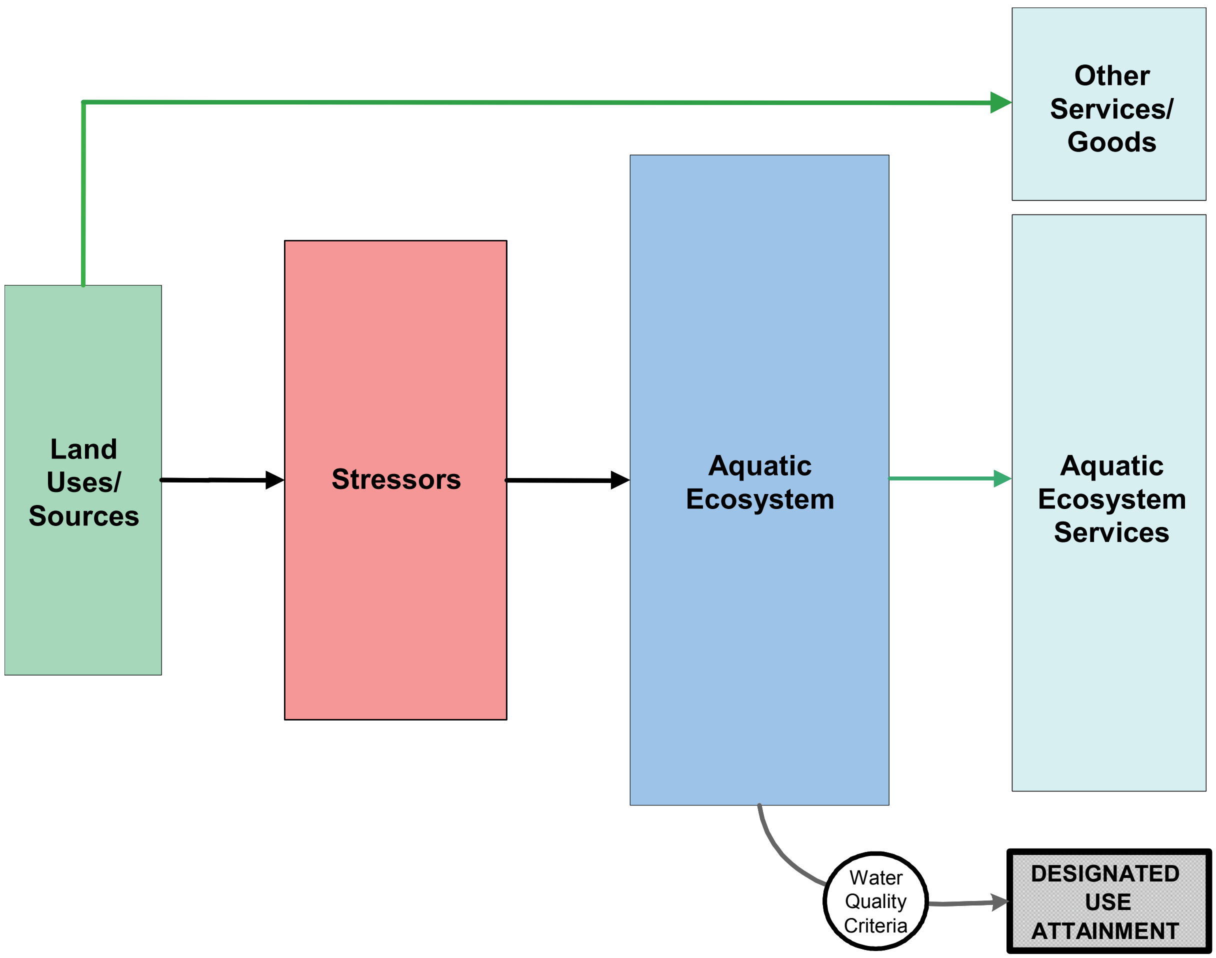


FIGURE 3-3

Effects of Sources/Stressors on Aquatic Ecosystem Services, Use Attainment and Provision of Other Goods and Services sources and land uses are also capable of providing other important goods and services to humans. For example, agricultural land uses may degrade water quality in local streams while at the same time providing valued food crops for consumers.

Figure 3-4 further extends the framework shown in Figure 3-3. It illustrates how management options considered in a standard-setting process, such as restoring a riparian area or building a stormwater retention pond, typically will alter the effects of land uses and other sources of impairment on human well-being. Because humans may experience both gains and losses as a result of these options, the figure also demonstrates the trade-offs that are inherent in the standard-setting process (shown by purple lines). By controlling stressors to the aquatic ecosystem (represented by the blue lines), a management option should improve certain ecosystem services, resulting in gains to individuals who value these services. At the same time, however, controlling stressors may impose losses on certain individuals. Some of these losses will result from the *direct* costs associated with controls (e.g., capital and operating costs for effluent treatment systems). Other losses will result from *indirect* costs, which are the value of foregone opportunities (i.e., “opportunity” costs). For example, restrictions on agricultural land uses will generally result in fewer goods being available from agricultural production.

In addition to illustrating the relevance of ecosystem services for evaluating WQS and the inherent gains and losses involved in the standard-setting process, Figures 3-3 and 3-4 show how these considerations are related to the attainment of designated uses. Use attainment is ultimately determined by comparing observed water quality (or related conditions) in the aquatic ecosystem with the relevant water quality criteria. Without a management option in place (Figure 3-3), water quality may well be degraded to the point at which specific criteria are not met and the corresponding designated uses are not attained. Once an option is implemented (Figure 3-4), water quality may improve to the point where the criteria are met and the designated use is attained.

3.4.2. Stages for Developing Expanded Conceptual Diagrams

Applying the general framework outlined above to evaluate specific WQS conditions requires gathering and organizing several types of information, first to characterize baseline conditions (based on Figure 3-3) and then to characterize the effects of alternative management

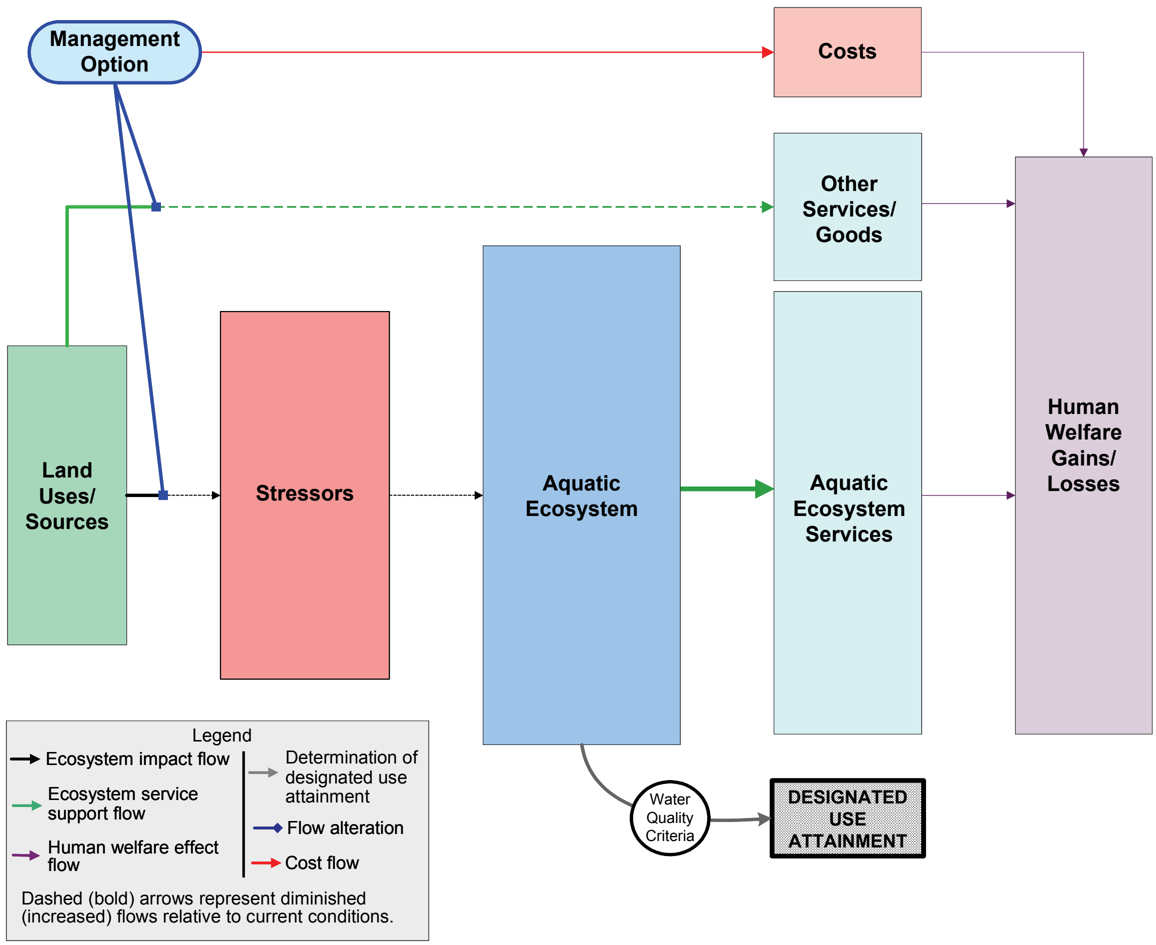


FIGURE 3-4

Effects of Management Options on Aquatic Ecosystem Services and Human Well-Being options (based on Figure 3-4). The following steps are recommended for these two development stages.

To characterize baseline conditions

(1) List the main ecosystem components and functions that are or could be affected.

(2) List and describe the activities (land uses and/or sources) in and around the water body that affect or could affect water body integrity.

(3) List the main stressors associated with each activity or source.

(4) Identify and show how these stressors are expected or known to enter and impair the ecosystem components and functions.

(5) List the services and goods that are or could be derived from the affected aquatic ecosystems as well as from the land uses and sources.

(6) List the designated uses for the affected water body and, in particular, identify the uses not being attained.

(7) Identify the ecosystem services (and other goods and services) that are or would be primarily affected by the identified land uses, sources, and stressors.

To characterize the relevant management decision

(1) List the management alternatives that will help attain designated uses.

(2) Determine the types of costs (including opportunity costs) incurred by implementing the management alternatives.

(3) Identify and show how the management alternatives will affect the sources and/or land uses and how they will alter the impacts of stressors on the ecosystem.

(4) Identify and show how the management alternatives will strengthen and/or weaken different ecosystem services (and other goods and service flows).

(5) Identify and show how the management alternatives will positively and/or negatively affect different aspects of human welfare.

Note that all of the steps outlined above are applicable for evaluating the results from both UAAs and ARs (see Chapter 2). With ARs, however, current conditions typically will involve fewer stressors than under alternative conditions, and the management decision typically will revolve around whether to allow additional stressors to enter the system. Therefore, the baseline characterization for ARs must be constructed in anticipation of the stressors (and related impacts) that would result if specific activities or sources were allowed to occur. For example, if the AR involves consideration of a mall development (as in Case Study 4 discussed below) that may increase sediment loads to a water body, baseline conditions will not include the mall as a source or the increased loads as stressors. Nevertheless, it is useful to represent the *absence* of these sources and stressors in the baseline conceptual diagram.

3.4.3. Case Study Examples of the Expanded Conceptual Models

This section presents several specific examples of expanded conceptual models that were developed based on the general framework and the development steps described above. These examples, which together comprise five "case studies," address the following hypothetical WQS scenarios:

- Case Study 1 presents a hypothetical UAA addressing acid mine drainage (AMD) impacts on a tributary stream and a river.
- Case Study 2 presents a hypothetical UAA addressing combined sewer overflows (CSO) and stormwater impacts on a river system.
- Case Study 3 presents a hypothetical UAA addressing agricultural impacts on an intermittent stream.
- Case Study 4 presents a hypothetical AR of a proposed retail development complex.
- Case Study 5 presents a hypothetical UAA addressing discharges to an effluent-dominated stream.

The purpose of these examples is to demonstrate how expanded conceptual models can illustrate key connections within and between aquatic ecosystems and humans and to evaluate the relevant impacts and gains and losses associated with alternative management options.[7]

Each WQS case study is introduced below with a written description of the key issues, conditions, and assumptions. Diagrams representing current conditions and one or more alternative management scenarios follow. To provide additional context for each case study, most of the conceptual flow diagrams are also accompanied by spatial diagrams that depict conditions in the affected water bodies (with and without the management options).

To represent current conditions, each case study includes a conceptual diagram based on Figure 3-3. These figures typically illustrate a sequence of effects, beginning with how specific sources (including land uses) contribute different stressors to the aquatic ecosystem. They then show how these stressors affect different components of one or more aquatic ecosystems and how these systems support a range of ecosystem services. Within the conceptual framework, they also depict designated use-attainment status under current conditions.

To represent the ecological and socioeconomic effects of different management options, each case study also includes diagrams based on Figure 3-4. First, they show how each management option affects the stress-related flows from sources to ecosystems, in most cases by reducing the negative impacts caused by specific stressors. Across the different management options, differences in the strength of these flows are represented by the format of the arrows, with dashed lines representing diminished flows relative to current conditions. The bold lines represent increased flows relative to current conditions. Second, they show the various ways (both positive and negative) in which the options ultimately affect human well-being. These gains and losses to humans are shown to result from changes to aquatic ecosystem services, as well as from the costs associated with implementing management options. They represent, in most cases, socioeconomic endpoints that are not addressed by the U.S. EPA's *Interim Economic Guidance*. The gains and losses in each of the human welfare categories (e.g., recreation values) are represented by a + or –. For these gains and losses in human welfare to exist, individuals must be aware or perceive that the changes have occurred. The number of + or – symbols shown

[7] Because all of the case studies are based on the general framework presented in Figure 3-3 and 3-4, a reader could understand the expanded conceptual model approach by examining only one case study. However, each presents unique aspects that cannot be found in just one case study and Chapter 5 uses Case Study 1 and Case Study 2 to illustrate the process presented in the report.

represents an ordinal ranking of the management options regarding their effect on the welfare category. For example, in Case Study 2 (depicted in Figures 3-8 through 3-10), compared with current conditions, Option 2 would increase the recreational value derived from the ecosystem. This increase is indicated by + for recreational value in Figure 3-10; however, Option 1 would cause an even larger increase in recreational value compared with Option 2. This larger increase is indicated by ++ in Figure 3-9.[8] Third, the diagrams depict the expected designated use-attainment status when a given management option is in place.[9]

3.4.3.1. *Case Study 1: Acid Mine Drainage (Figures 3-5 through 3-7)*

In the early 1900s, parts of Pennsylvania and West Virginia prospered because of the extraction of coal. Since then, coal mining has declined and adverse environmental impacts have increased (especially from abandoned mine lands).

A tributary to a popular recreational river is a major source of AMD. The drainage from the surface mining and tailings has low pH from contact with pyrite (an iron sulfide) and has elevated levels of metals; AMD can contaminate drinking water sources, eliminate habitat and aquatic life, and corrode infrastructure like bridges. The tributary has designated uses of aquatic life, secondary water contact recreation, and agricultural water supply; the river has aquatic life (warm water), primary contact recreation, and agricultural water supply. These designated uses are not being met in particular stretches of both the tributary and the river.

The tributary is about 7 miles long and receives AMD from surface runoff linked to abandoned mine lands and mine tailings (this occurs 3 miles from the headwaters). Two seeps are visible from the tailings. Aquatic life, like fish and salamanders, are not found in the tributary after the drainage enters it.

The river, which has many activities affected by the AMD, is considered dead for 8 miles after the tributary enters it. However, the tributary is not the only cause of degradation in the river. Several smaller nonpoint sources of AMD also directly discharge into the river along this 8-mile stretch and contribute to poor water quality in this part of the river. Aluminum

[8] The number of + or – should **not** be interpreted or used to compare changes across human welfare categories (for example, more pluses for recreation values compared with consumption values does **not** necessarily mean that the gains through recreation are greater than those through consumption). Also note that two +'s does not necessarily indicate twice the increase; such quantitative evaluations are generally not possible at this stage.

[9] Stating that the diagrams depict the expected designated use-attainment status means that management options might fail. In Case Study 1, a probability that the option will fail is given in the text. In the other case studies, the diagrams show the expected results if the management options do not fail.

concentrations prevent any fish population from existing in this part of the river; however, the riparian habitat is of good quality and other wildlife is abundant.

A number of activities and land uses occur in the vicinity of the river and tributary. The river is known for its whitewater rafting and kayaking. Hiking, mountain biking, and picnicking are popular around both the river and tributary, especially along a recently completed rail-trail that follows the river and crosses the tributary. Most recreationists are not from the local area. The tributary and river are not a source for drinking water, but the tributary (above the AMD) supports some stock watering. Forests and pastures are the primary land uses in the watershed. The tributary has 10 houses near it, and 300 houses are within 5 miles of the impaired river.

In addition to considering TMDLs for aluminum, iron, and pH, the state also has conducted a UAA for the tributary and part of the river. In the UAA, the state estimated the costs of restoring both the entire segment of the tributary and the affected portion of the river. Based on an analysis of "substantial and widespread economic and social impact" (Factor 6), they have determined that they cannot afford to conduct all the restoration. In addition, the state has determined that the tributary produces more AMD than the combined discharges from the other nonpoint sources that directly affect the river. The results indicate that the costs of restoring the tributary would be considerably less than controlling the nonpoint sources along the river.

Based on the UAA, the state has decided to focus on restoring the tributary. Several methods are available to raise the pH of AMD-contaminated water from the tributary; however, the two most promising methods available to mitigate the effects of AMD in the above-mentioned reach are a limestone channel and constructed wetlands.

The first option is to install an open limestone channel and settling pond. A small dam is created before the seeps enter the channel to trap sediment and other debris. The channel includes a limestone sand liner and limestone rocks. With a pH of 4.0, the water flows through the channel to a settling basin. The treatment is expected to last 20 years, and noticeable differences in the tributary are likely to begin in year 1. However, there is a 10% chance the system will fail to meet the tributary's water quality goals. This option is expected to cost \$100,000 including excavation costs and land costs. Maintenance costs will be about \$2,000 per year after year 1. After 10 years, new limestone rock may be necessary at additional cost.

The second option is to construct a series of wetlands on a large area of land, just before the seeps enter the tributary, which could be built to reduce metals and AMD. First, after flowing into a settling pond, a smaller wetland reduces flow and causes metals to precipitate out. The larger wetland further reduces flow velocity and metals; a final settling pond is used for any remaining precipitation. To adequately increase pH, it will be necessary to augment this system with additional alkalinity. The chance of complete failure of this type of system is about 30%. These wetlands are expected to last 20 years, but the noticeable differences in the tributary will only begin to occur starting in year 3. The cost of the wetlands is expected to be $200,000, which includes land purchases and maintenance costs of $500 per year after year 1.

Both management options will eventually allow the tributary to support aquatic life, but few anglers will fish it because of private property restrictions. Restoration of the tributary will improve the overall aesthetic value of whitewater rafting and kayaking in the river; an additional 1000 person-days per year of kayaking (e.g., 250 individuals kayaking an additional 4 days) are expected. Both options will also allow part of the impaired portion of the river to meet its warm-water aquatic life (e.g., smallmouth bass) criterion; however, the other nonpoint sources of AMD on the river will still affect the river quality beyond those restored miles. Property values are expected to increase slightly with either alternative, although there may be an issue related to wide construction "rights of way" for either the limestone channel or wetlands. There is a small possibility that new construction of houses and cabins could occur with the restoration.

With the limestone channel, no additional wildlife habitat will be created near the tributary. However, the limestone channel will provide more buffer capacity for the river than the wetlands. The river is expected to meet its warm-water aquatic life use for 3 miles after the tributary enters it if the limestone channel is used and only 2 miles for the series of wetlands. Given the popularity of fishing in the area, the additional 3 miles that meet warm-water aquatic life could create approximately 200 person-days of recreational fishing. Fewer person-days of recreational fishing on the river are expected if wetlands are constructed and only 2 miles are restored.

In contrast to the limestone channel, the constructed wetlands will create additional wildlife habitat, which will enhance recreational and other activities near the tributary. In particular, users of the rail-trail (hikers, bikers, and picnickers) will benefit from the new ecological resource; as a result, an additional 750 person-days per year of hiking, biking, and picnicking are expected. In addition, the wetlands are expected to reduce sedimentation in the tributary and reduce flood potential through surface water storage.

Stakeholders include recreationists, a watershed group, homeowners, and the state department of environmental protection (DEP). The watershed group would like to move forward with its watershed plan that would achieve water quality goals in the entire river, but it lacks sufficient funds for reaching the water quality goals.

Data Available. The state DEP collects information on certain water bodies that are impaired and require TMDLs. Researchers at a nearby university are undertaking a number of studies related to AMD in the area. A local watershed group has developed a watershed plan that describes issues related to AMD throughout the watershed, not just the tributary and specific stretch of the river.

Additional Assumptions

- The only two significant sources of stressors on the tributary and the 8-mile portion of the river are abandoned mines and surface runoff (sedimentation).
- Healthy riparian habitat in the tributary and river helps control surface runoff and prevent flooding downstream.
- The only significant service provided by the bridge is transportation, and the main cost associated with corrosion is more frequent maintenance.
- As long as the two management options do not fail, both will allow for all designated uses on the tributary and river to be met, with the exception of warm-water aquatic life use in the river, which will still be affected by other sources of AMD.

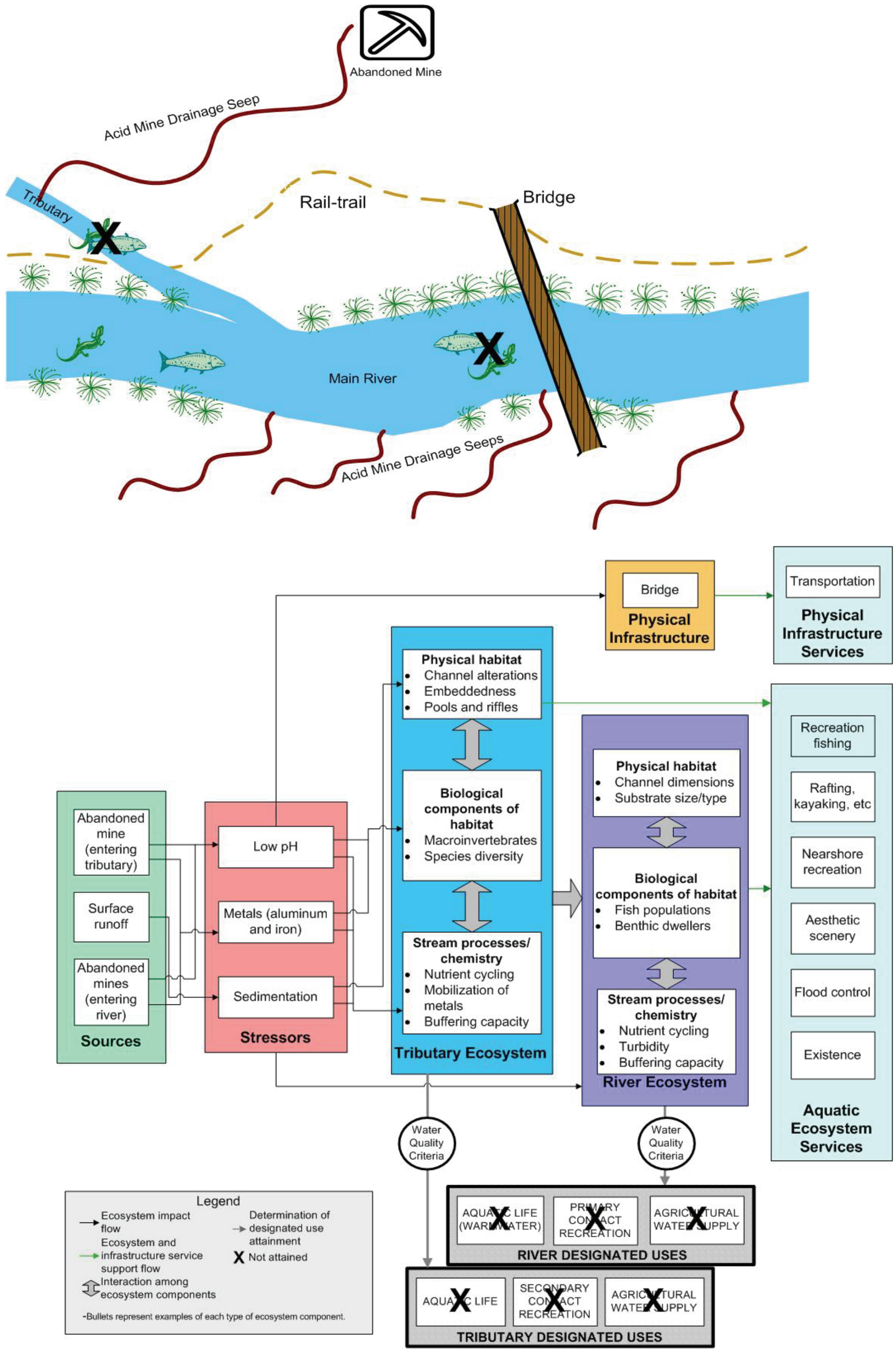


FIGURE 3-5

Mitigating Acid Mine Drainage Impacts on a Tributary and River: Current Conditions

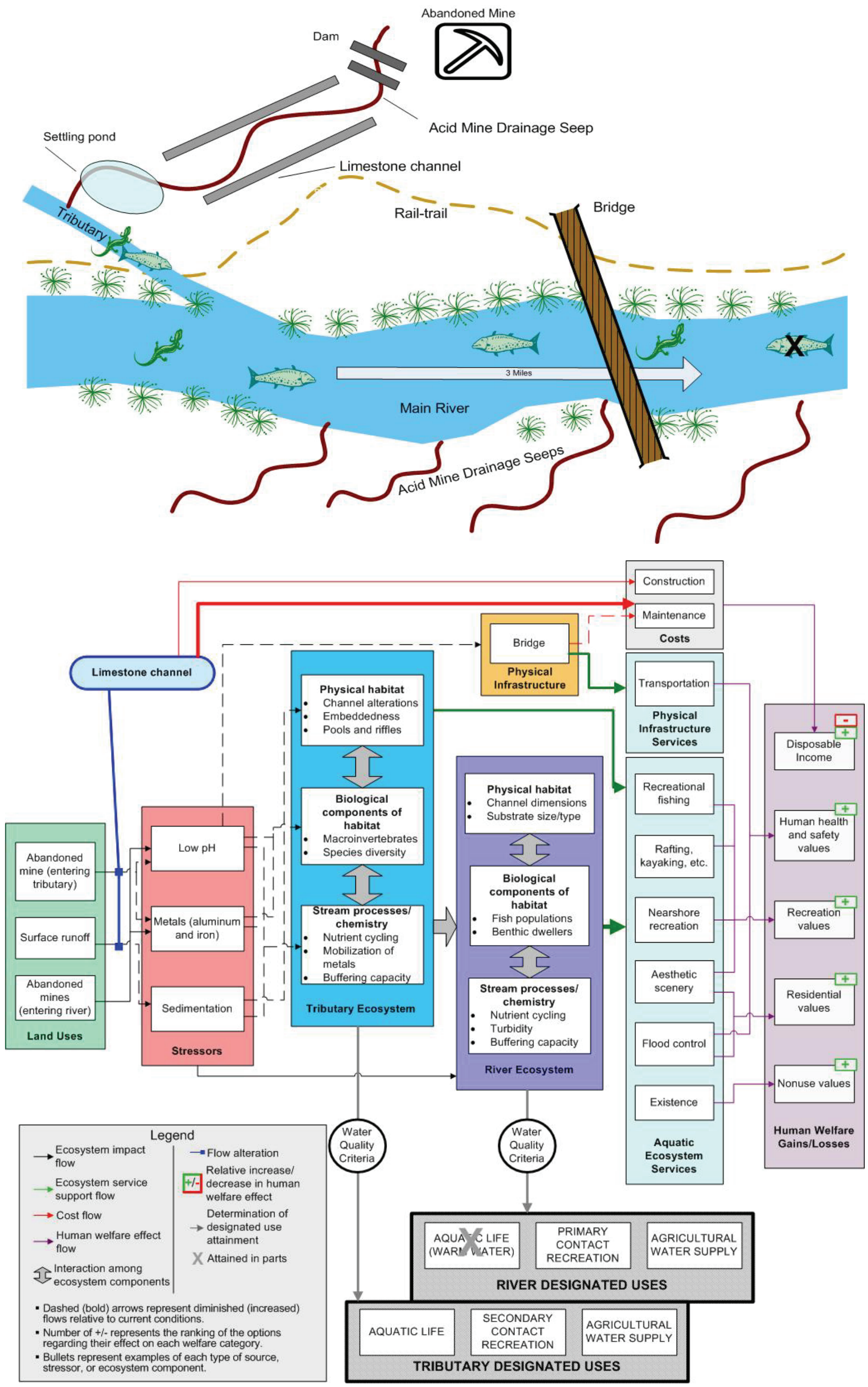


FIGURE 3-6

Mitigating Acid Mine Drainage Impacts on a Tributary and River:
Option 1: Create Limestone Channel

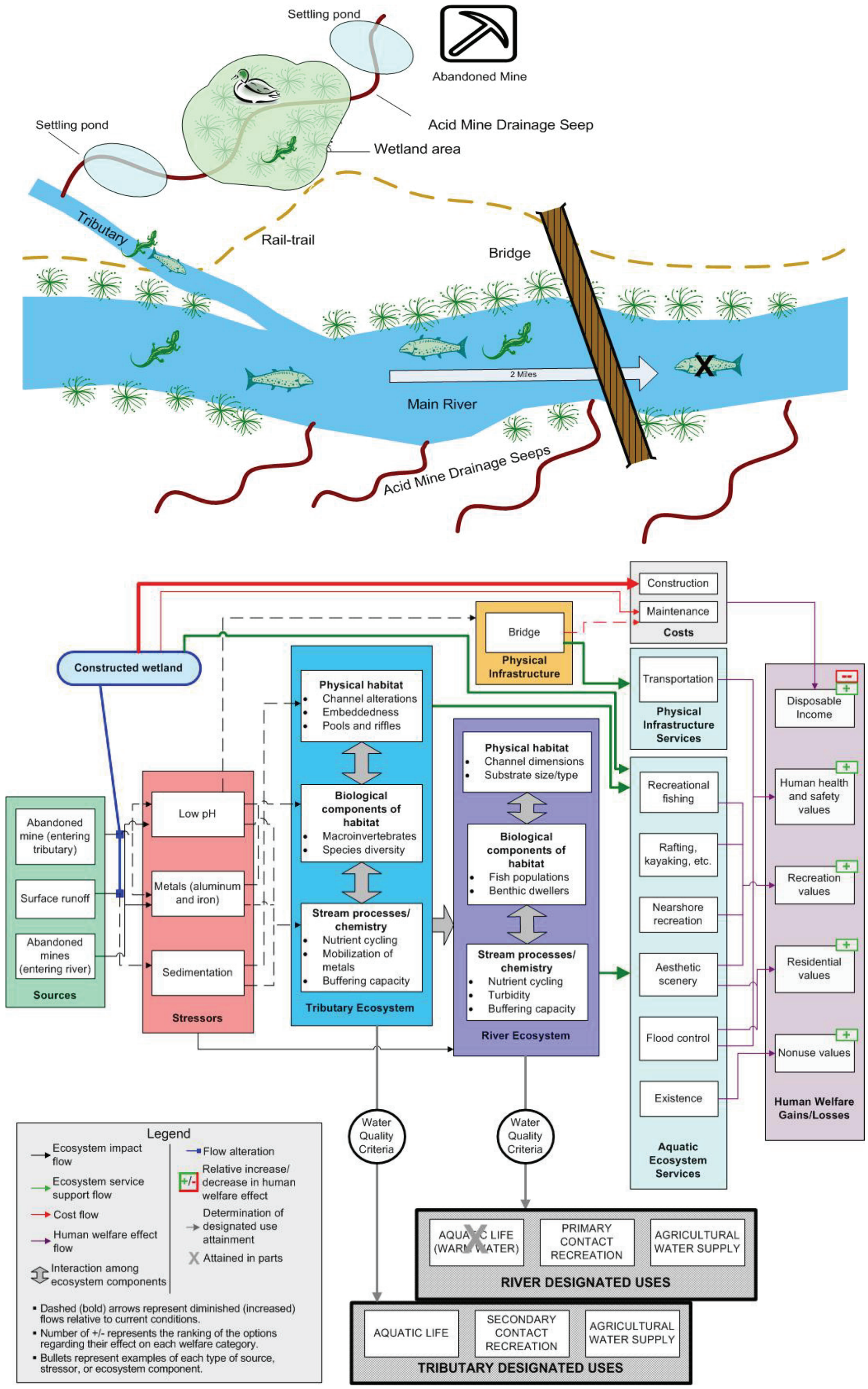


FIGURE 3-7

Mitigating Acid Mine Drainage Impacts on a Tributary and River:
Option 2: Create Wetland Area

3.4.3.2. *Case Study 2: Hypothetical Combined Sewer Overflow (Figures 3-8 through 3-10)*

A large river flows through multiple states; an interstate Basin Commission is responsible for improving the river's water quality. CSO events are a major source of pollution, especially for the urban areas located near the river (with a population of approximately 2 million people). The CSOs carry both sewage and stormwater to wastewater treatment plants (WWTPs), but, during wet weather events, can overflow directly into streams and rivers releasing millions of gallons of raw sewage. Untreated sewage and stormwater pose potential threats to human health (especially through direct contact). A total of 120 CSOs discharge directly to this stretch of the river and overflow during approximately half the number of annual rainfall events.

Designated uses for the river are public and industrial water supply after treatment, primary contact recreation (e.g., full-body contact such as swimming, canoeing, kayaking, jet skiing, and water skiing), secondary contact recreation (e.g., incidental contact such as fishing), and aquatic life use. The Basin Commission is considering whether its current standards are appropriate for the CSO problem. They are considering a UAA related to Factor 6 (see Section 2.2), widespread social and economic impact, to determine if primary contact recreation is attainable.

For this particular stretch of the river, the bacteria criterion, which protects the primary contact recreation use, was exceeded 30% of the time in the previous year. Secondary contact recreation and public water supply were always supported during this time. Besides CSOs, however, stormwater discharges, sewer leaks, and urban runoff are also sources of the problem. Although the river is suitable for primary contact recreation some of the time, it does not meet the current WQS. In addition, biological monitoring suggests that aquatic life uses are only partially supported for this stretch (i.e., one biological criterion out of three is not achieved); however, recent improvements in fish community health can be seen (with more native and pollution-intolerant species). Sediments and scour are the main stressors on aquatic life.

Recreational surveys were conducted and found that recreational motor boating is the most popular recreational activity, followed by fishing. Canoeing and kayaking were also conducted on the river. Swimming was limited to only a few areas, even though there are no designated beaches on this river.

Two potentially feasible options are being considered to address the nonattainment of primary contact recreation use: (1) attempt to meet bacteria standards through an extensive set of improvements (it is unclear if meeting the standards is feasible because of the influence of sources other than CSOs) and (2) implement fewer improvements and create a limited use subcategory of contact recreation during wet weather (other alternatives were considered, but these two were found to be the most feasible). The costs for both of these options will be passed on to local residents and businesses through increases in sewer rates.

A combination of expensive methods is necessary to attain the primary contact recreation use. Increasing sewer capacity and storage, eliminating 95% of the CSO structures, separating sewer lines, and installing disinfection capabilities in the system will need to take place over a 10-year period. Improvements that are expected include reduction of bacteria and other pollution, removal of floatables and other debris, improved aesthetics, and control of odors. This is expected to be extremely costly (some estimate a three-fold increase in sewer rates) because of construction, materials, and surface disruption (e.g., roads and railroad beds would be torn up). Disinfection capabilities may require additional evaluation because disinfection may create disinfection by-products that might create additional health problems or harmful effects to aquatic life.

The second option, which is less expensive, is to eliminate 75% of the CSO structures and change the WQS to include a wet weather limited use subcategory for primary contact recreation. These changes would improve water quality in the river surrounding wet weather events. They would reduce but not eliminate the number of exceedances of the current bacteria criterion for primary contact recreation. Therefore, the designated use for primary contact recreation would be suspended during and immediately following (maximum 4 days) specific types of severe storm events. Instead, a limited use subcategory of primary contact recreation and related bacteria criterion would be applied during severe wet weather events. This option is significantly less costly than the first (it will require roughly a 50% increase in sewer rates) and will take only 5 years to implement. A notification system would provide information on days when sewer overflows are expected. Advisories would be issued by e-mail, local radio, a Web site, and a telephone information line. The notification system would be used to announce when the designated use for primary contact recreation is suspended because of potential human health threats from CSOs and other wet weather discharges.

Stakeholders include local communities, recreationists, states, the Basin Commission, local businesses, economic development groups, and watershed groups. It is unclear how stakeholders will perceive the contact recreation alternatives. Some may think that the Commission should not lower WQS because downgrades will eliminate some of the incentives to remove CSOs. They also may believe that primary contact recreation is important on the river. Tourism may be affected because of poor aesthetics during high flows (e.g., the presence of floatables). However, the cost of the CSO controls required to achieve the water quality goals might be excessive (and passed on to local homeowners and businesses) compared with the benefit gained (e.g., even if the bacteria criterion for primary contact recreation were met, swimming would not be advisable for safety reasons because of high flow). Current businesses may choose to leave the area, and new businesses may not move into the area if sewer rates become too high, which would have negative economic effects in the region. Although limiting recreational use during wet weather may not be acceptable to local communities, recreationists, and watershed groups, it avoids the large costs.

Data Availability. The Basin Commission for the river focuses on reducing pollution. They have collected extensive water quality data for the river, and a local university has collected data on the health of aquatic species community including types of algae. A number of watershed groups have formed in the area, each of which collects water quality data in their particular watershed.

Additional Assumptions

- In addition to CSOs, sewer leaks, stormwater discharges, and urban runoff along the segment of the river being evaluated, upstream sources of pollutants also contribute to water quality impairments in the segment.
- Option 1 and Option 2 would only reduce discharges from CSOs (not from the other sources of stressors).
- Option 1 and Option 2 would lead to reductions in episodic loadings of sediments and scour from CSOs sufficient to meet all three biological criteria for the aquatic life designated uses.
- The costs of Option 1 and Option 2 ultimately would be borne by local residents and businesses (e.g., through sewer rate increases), whose incomes, and therefore consumption levels, would decrease.
- Option 1 and Option 2 would reduce pathogen-related risks in the public water supply.
- Risk of human illness for Option 1 is lower than in Option 2.

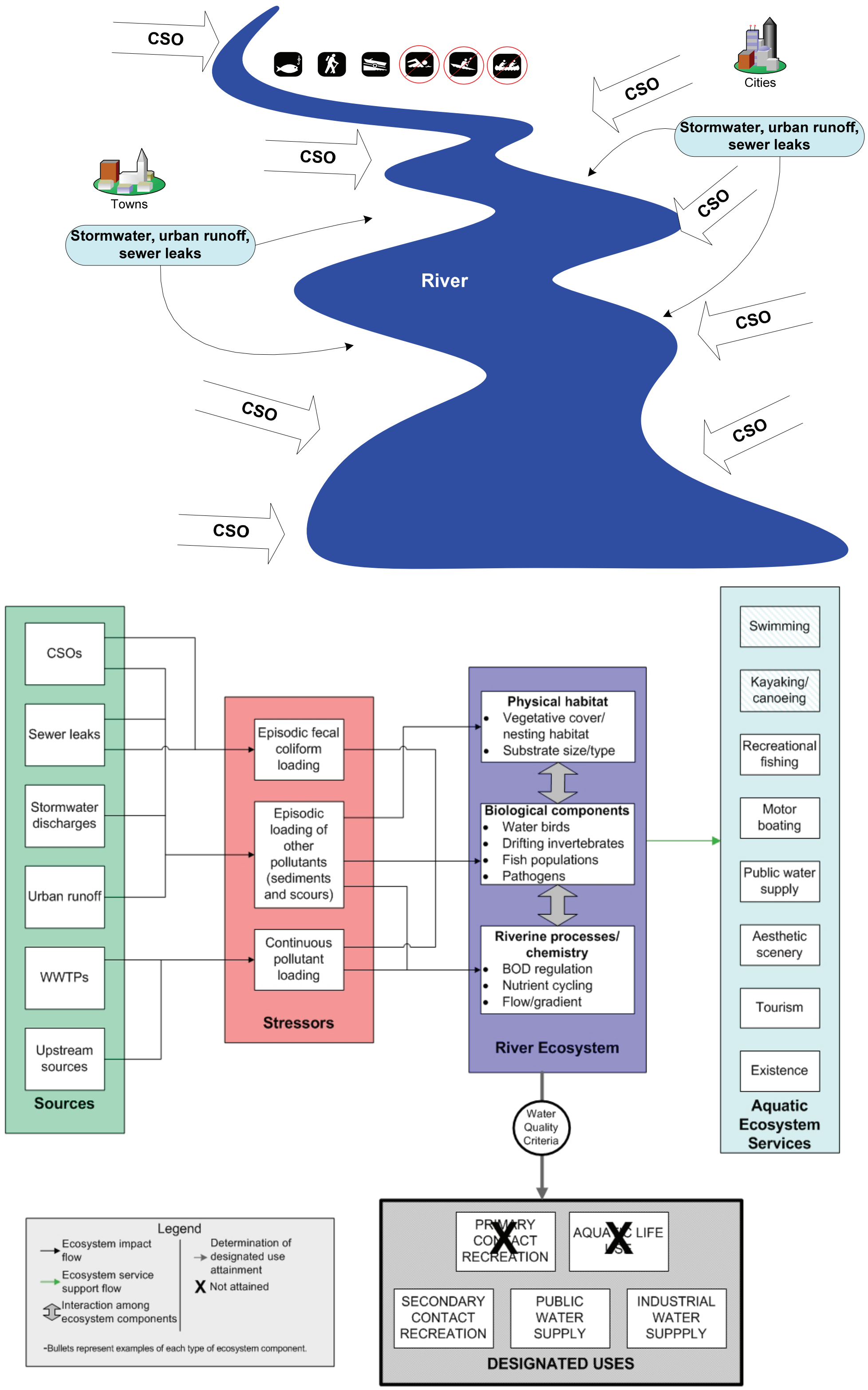


FIGURE 3-8

Mitigating CSO and Stormwater Impacts on a River System: Current Conditions

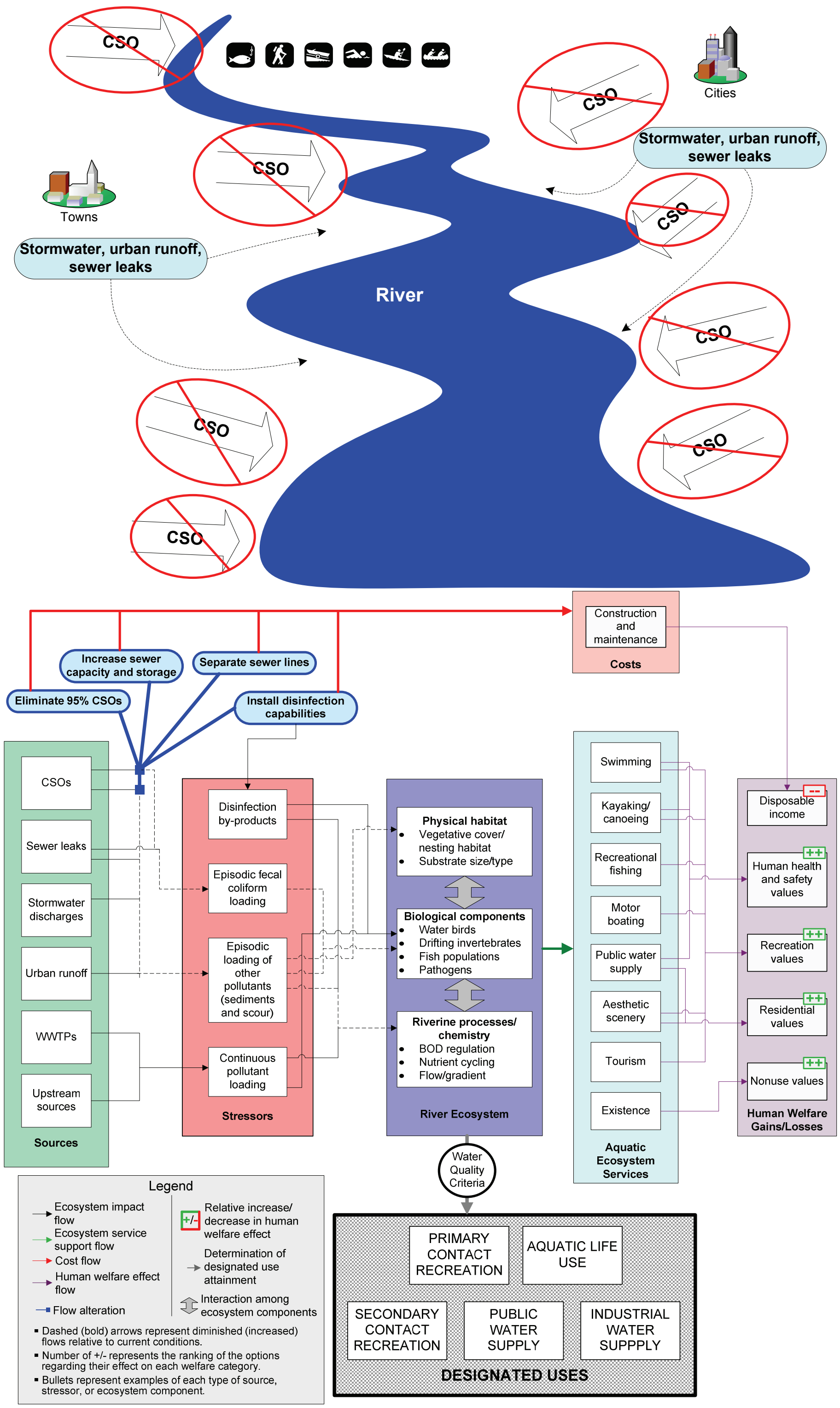


FIGURE 3-9

Mitigating CSO and Stormwater Impacts on a River System:
Option 1: Eliminate 95% of CSOs and Implement Other System Improvements

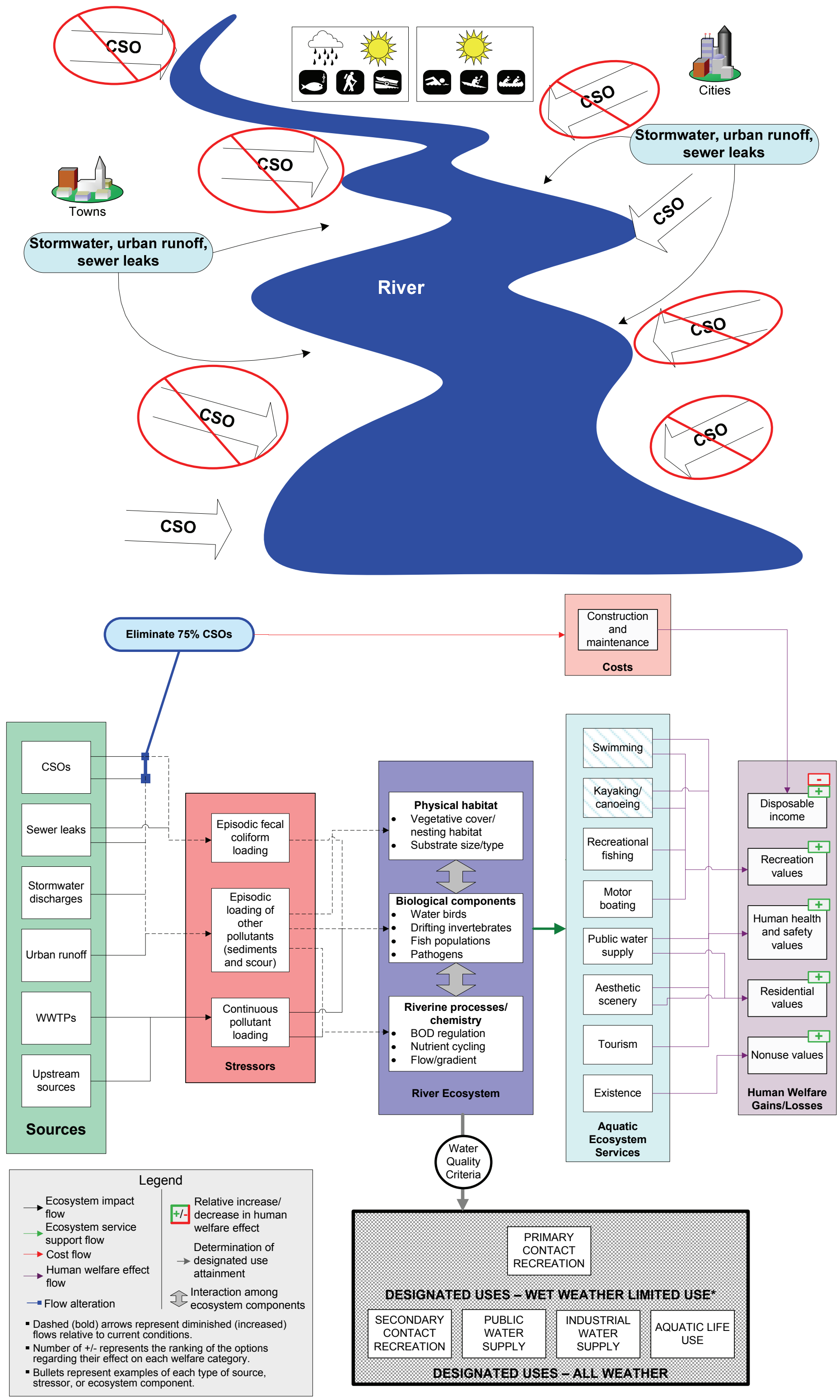


FIGURE 3-10

Mitigating CSO and Stormwater Impacts on a River System:
Option 2: Eliminate 75% of CSOs and Apply Limited Use Designation

3.4.3.3. *Case Study 3: Mitigating Agricultural Impacts on an Intermittent Stream (Figures 3-11 through 3-14)*

An intermittent stream is designated as a secondary-contact recreation water segment and aquatic life use water body. The segment is privately owned and is used to water livestock during periods of flow. The landowner has given permission to the public to hunt and trap along the segment. The primary land uses around the segment are livestock grazing and growing crops. The livestock have direct access to the stream and therefore modify the habitat by preventing regrowth of the riparian buffer and destroying the river bed. Direct access to the stream also leads to direct deposit of animal wastes into the stream. Water quality measurements taken on the segment suggest these stressors lead to increased temperature, low DO, downcutting of the channel, and increased sediments. The biological criteria are violated for aquatic life use because of the stressors and possibly because the criteria are based on perennial streams (not intermittent streams). Landowners downstream are complaining that the poor condition of the intermittent stream segment is affecting recreational fishing on their segments. Algae, sediment, and nutrients are their biggest complaints.

Options to restore this intermittent stream include fencing off livestock access to the stream and constructing either a stone crossing (Option 1) or culverts and bridges (Option 2) so the livestock can have access to the fields across the stream. Benefits include improvements to fish and wildlife habitat as stream side plants are reestablished, as well as fewer animal injuries and healthier animals for the landowner. The landowner, however, will lose access to some grazing lands because of fencing off the riparian area around the stream. Another activity and stressor on this same stream segment is growing crops around the stream. Aquatic life use standards might not be met by preventing direct access to the stream alone; the agriculture runoff associated with the cropping activities also may need to be reduced. The crops prevent any type of riparian buffer to grow, and runoff enters the segment directly. Some of the activities to prevent livestock access may help, but further restoration of riparian areas may be necessary (Option 3).

Key Assumptions and Additional Considerations

- Improving the quality of the riparian area for the intermittent stream will reduce the runoff into the stream and promote greater infiltration during rain events. This will result in less “flashy,” event-driven streams and regulate downstream flow, perhaps providing some degree of flood control.

- Improving the quality of the riparian area will result in greater channel stability through healthier vegetative cover along the stream banks. This will result in more diversity in habitats (e.g., through woody debris) and higher DO as a function of temperature regulated by overhanging vegetation.

- Residential properties are located downstream along the perennial stream, so residents would benefit from improved aesthetics and flow/erosion control.

- The perennial stream is used for various types of recreation and potentially for drinking water as well.

- Hunting and trapping along the intermittent stream would be improved only in Option 3 when livestock are fenced off and the riparian area is fully restored.

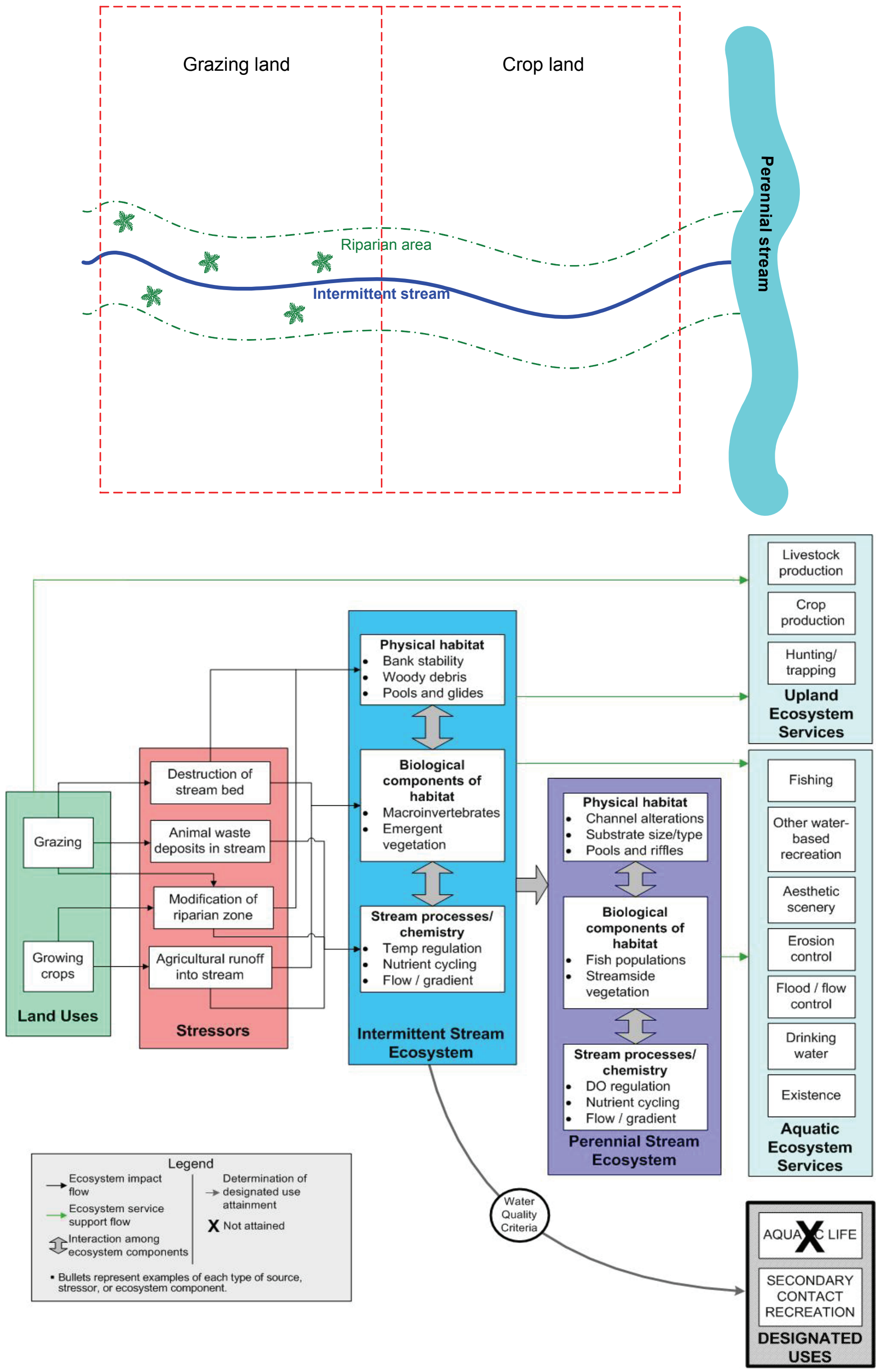


FIGURE 3-11

Mitigating Agricultural Impacts on an Intermittent Stream:
Current Conditions

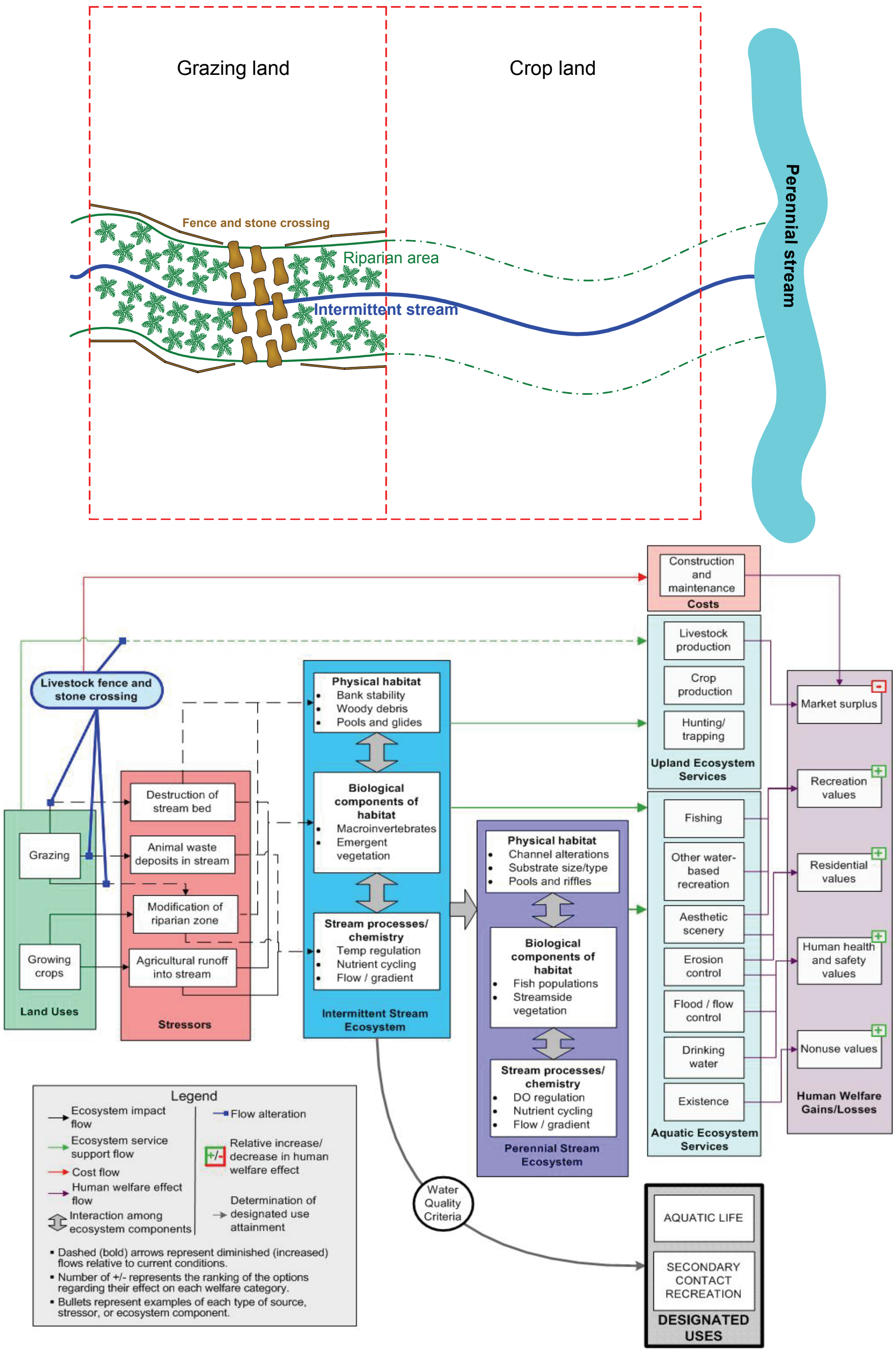
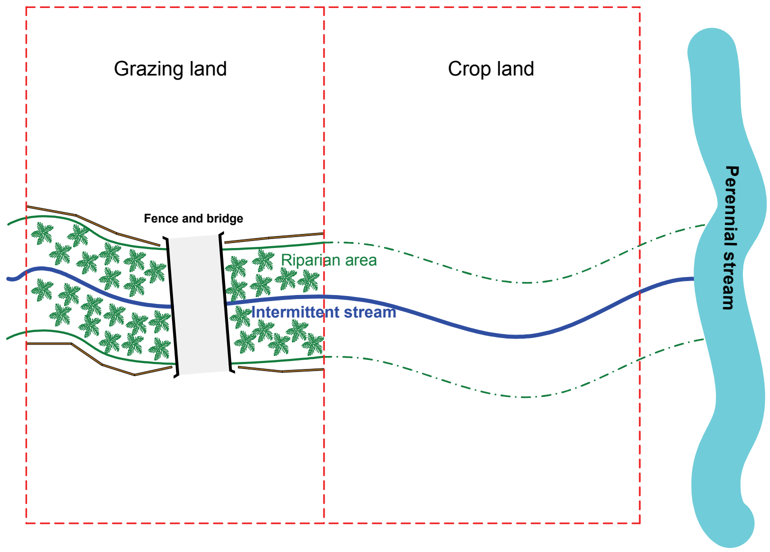


FIGURE 3-12

Mitigating Agricultural Impacts on an Intermittent Stream:
Option 1: Limiting Livestock Impact with Fence and Stone Crossing



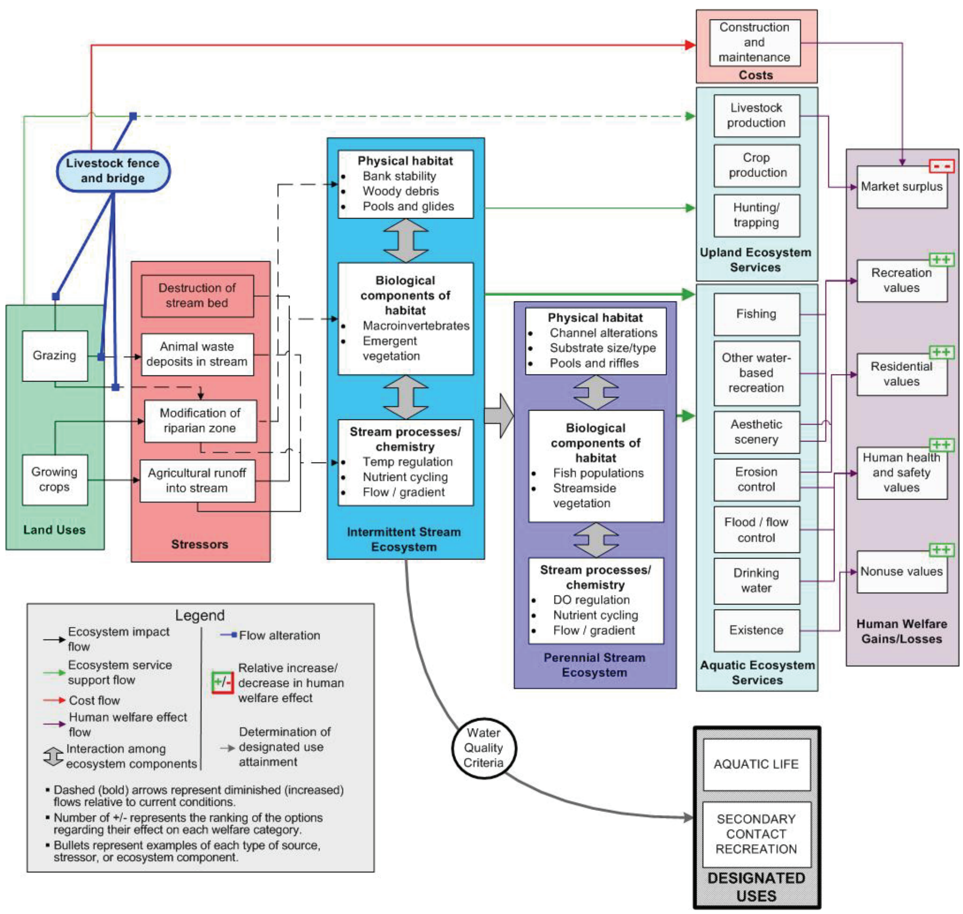


FIGURE 3-13

Mitigating Agricultural Impacts on an Intermittent Stream:
Option 2: Limiting Livestock Impact with Fence and Bridge

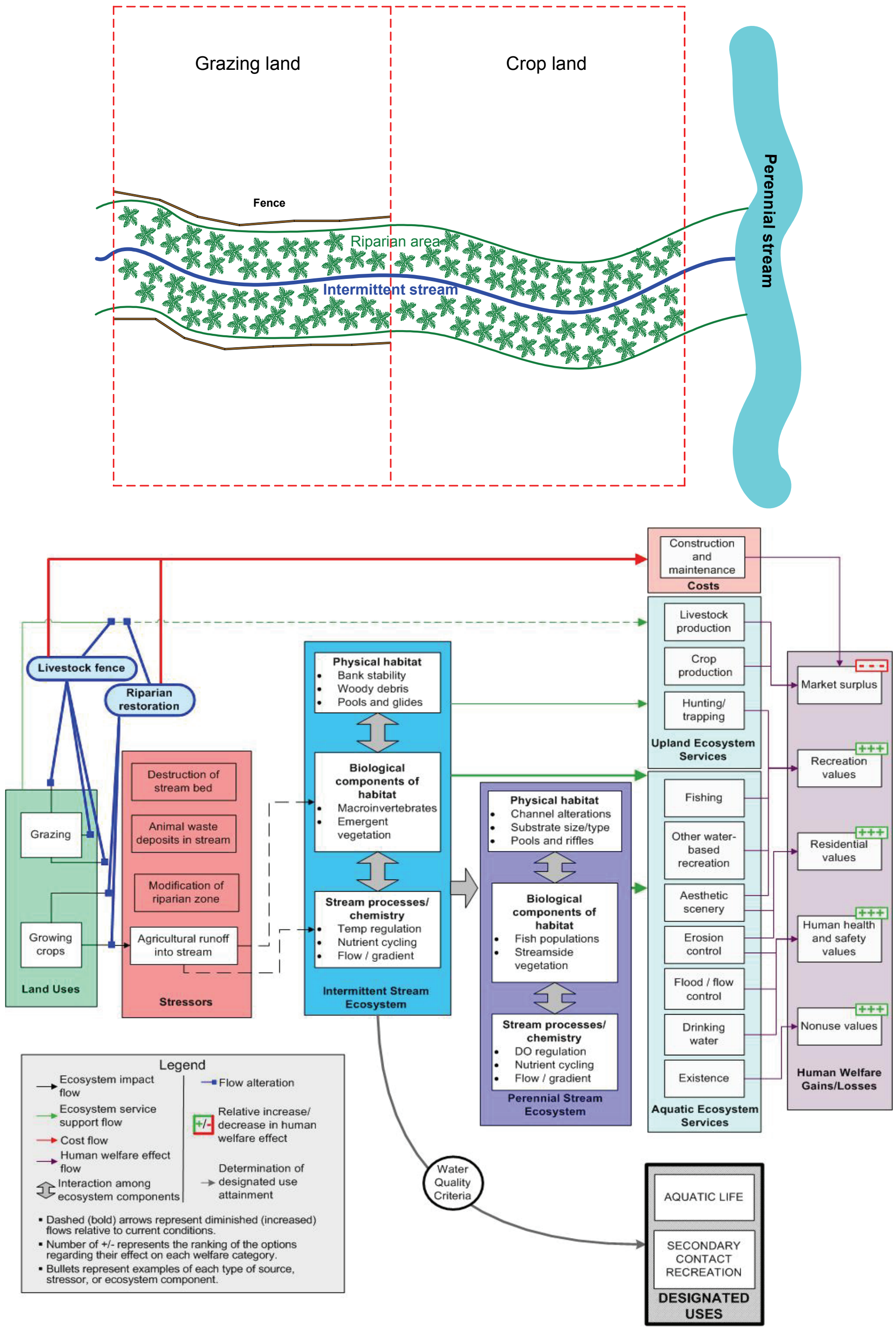


FIGURE 3-14

Mitigating Agricultural Impacts on an Intermittent Stream:
Option 3: Limiting Livestock and Crop Impact with Fence and Riparian Restoration

3.4.3.4. *Case Study 4: Antidegradation Review of Proposed Retail Development Complex (Figures 3-15 and 3-16)*

A new retail development complex is being located in a small watershed, and an antidegradation tier 2 review is necessary. For the complex to be located on an upland area of the property, a road must cross a wetland. For the roadway to be built, 0.5 acre out of 20 wetland acres must be filled. This wetland, which provides habitat for birds, is connected to a stream where current water quality is above standards for a cold-water fishery. The AR will determine whether maintaining water quality will preclude important economic and social development. No other potential location for the road exists, and the developers believe this is the best location for the complex. Given the proposed location of the new road, the main stem of the watershed may be affected by increased sediment load. The construction of the retail complex will initially increase sedimentation to the wetlands. Along with the installation of stormwater detention ponds, revegetation of the area will enable sedimentation to decrease and preconstruction conditions to return. However, the road will lead to a permanent lowering of water quality to the fishable stream (but still meet the WQS). The complex and road construction are predicted to lead to new jobs and improved living conditions within the watershed.

Key Assumptions and Additional Considerations

- Under conditions without the retail development, the upland area would primarily provide open space, which would provide some recreational opportunities and aesthetic amenities to local residents.
- Even with the construction of stormwater retention ponds, the retail area would be a long--term source of sediment loads (although less than would occur without the ponds).
- Residential properties are located downstream along the perennial stream, so residents would benefit from improved aesthetic conditions and flow/erosion control.

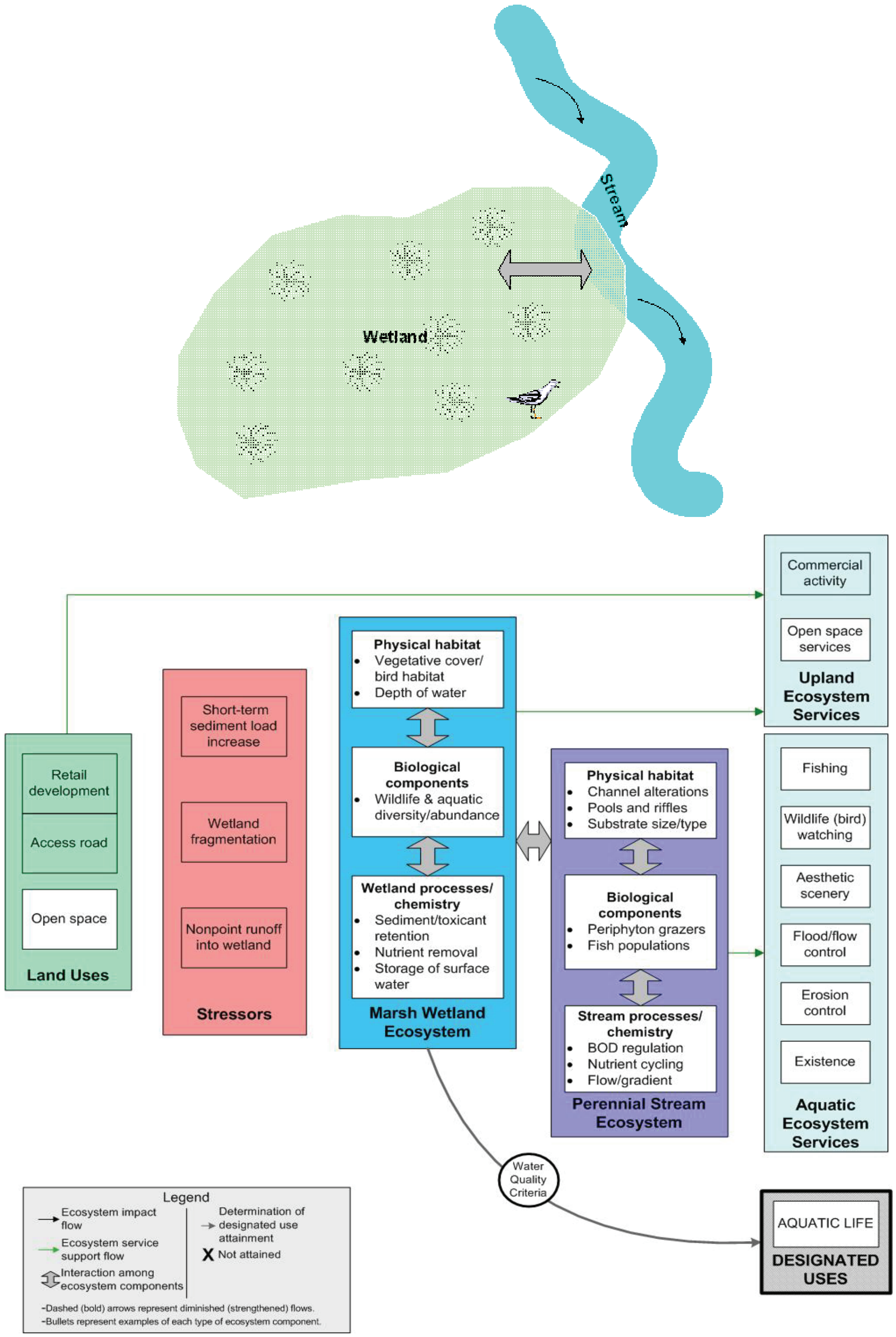


FIGURE 3-15

Antidegradation Review of Proposed Retail Development Complex Conditions Without Retail Development

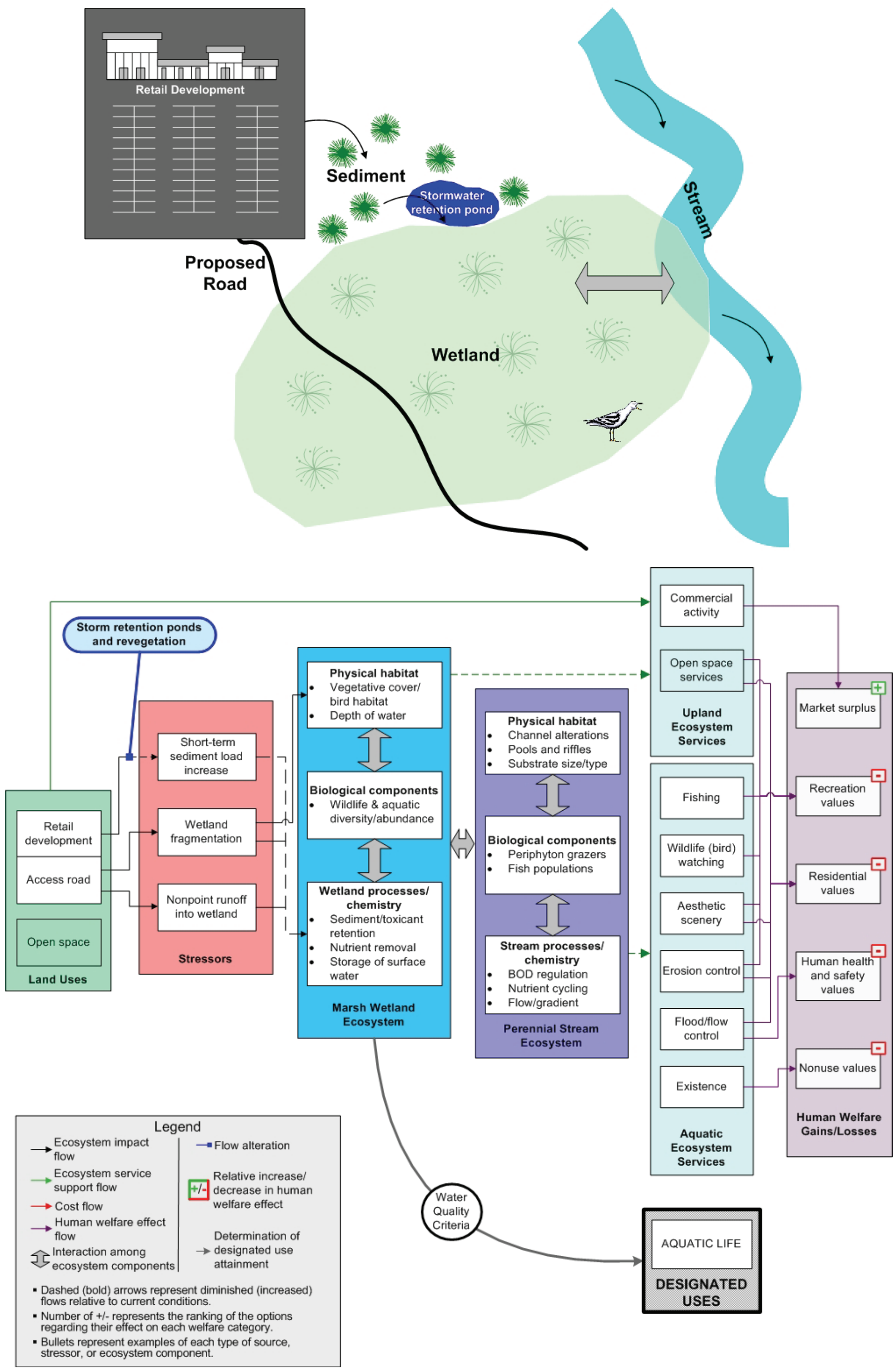


FIGURE 3-16

Antidegradation Review of Proposed Retail Development Complex
Effects of Retail Development

3.4.3.5. *Case Study 5: Management of an Effluent-Dominated Stream (Figures 3-17 through 3-19)*

A state has recently changed its designated uses for intermittent and ephemeral streams to include aquatic life. Because the state did not originally designate aquatic life uses on intermittent and ephemeral streams, many industries and wastewater facilities located on these streams to dispose of their discharges. These intermittent streams are now effluent dominated. One wastewater treatment plant's discharge has converted an ephemeral stream into one with perennial flow. It has developed a riparian area that has created new habitat for birds, wildlife, and amphibians and is a source of groundwater recharge. One rare salamander has been found in and around this stream. This particular stream is a tributary to a major river and supports the river's beneficial uses of warm-water aquatic life and primary recreation. The continuous flow of the effluent-dominated stream has also created a bird-watching area around the stream. With the new designated uses, these facilities have a limited number of options to deal with the new classifications. Pollutants that may violate aquatic life standards include metals, disinfection by-products, pH, temperature, and DO. The facilities could increase treatment to meet the new standard (Option 1) or they could cease the discharge (and effectively relocate) (Option 2). Each of these possibilities would lead to different benefits and costs to the facilities and to society.

Key Assumptions and Additional Considerations

- The cost of advanced treatment or relocation of the wastewater treatment plant would ultimately be borne by local residents (e.g., through taxes), whose incomes, and therefore consumption levels, would decrease.
- The costs of advanced treatment installation or the closure of industrial dischargers would result in lost incomes and/or higher prices for market goods. In either case, consumption levels would decrease.
- Elimination of point sources (Option 2) would reduce water flow and pollutant discharges to the stream segment; however, these point sources (in particular, the wastewater treatment plant) would need to relocate to other water bodies, where similar ecosystem impacts might be experienced (these similar impacts are not included in the conceptual model).
- Elimination of point sources (Option 2) would return the stream to intermittent flow conditions, which would provide a different and perhaps more limited set of ecosystem services.

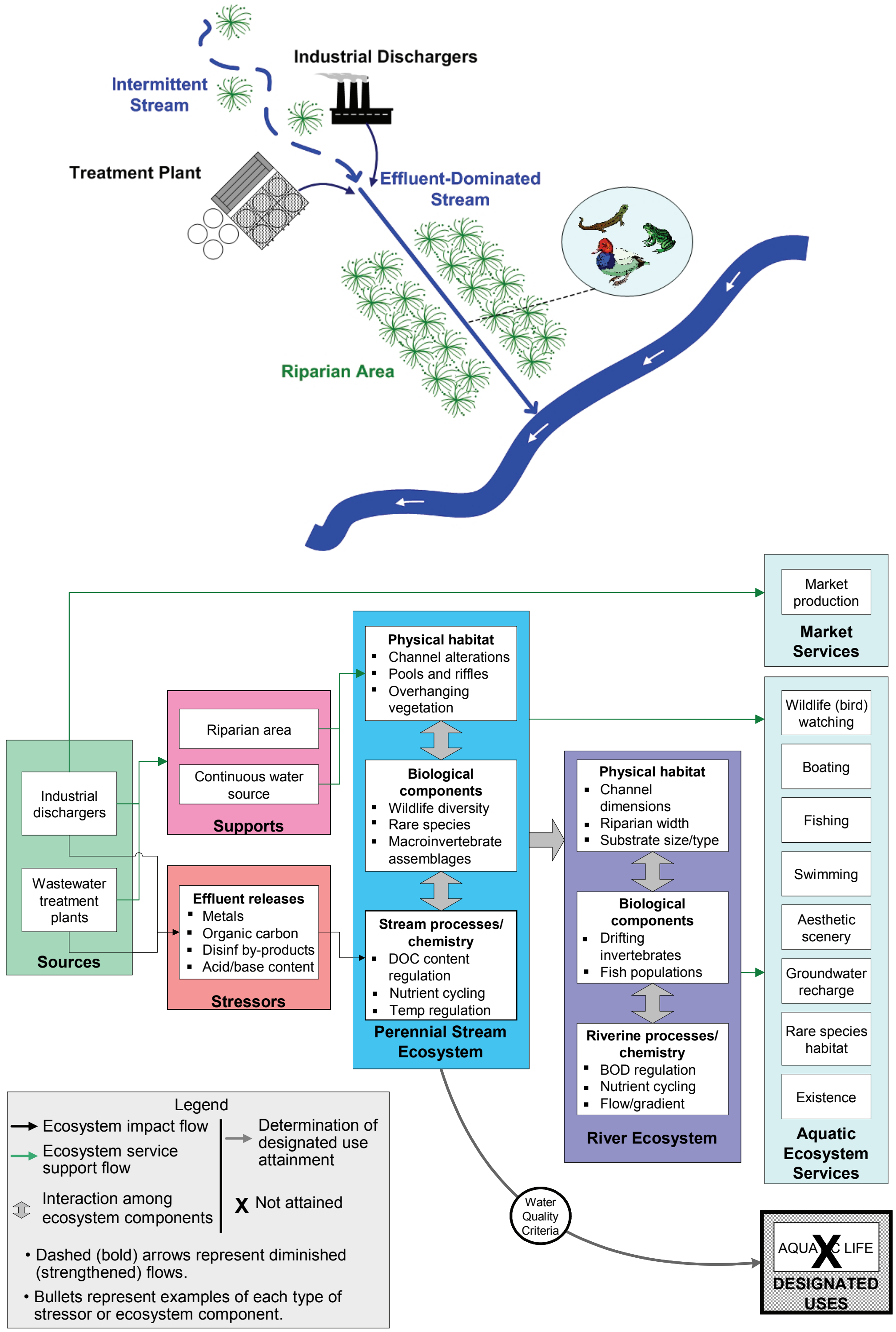


FIGURE 3-17

Management of an Effluent-Dominated Stream:
Current Conditions

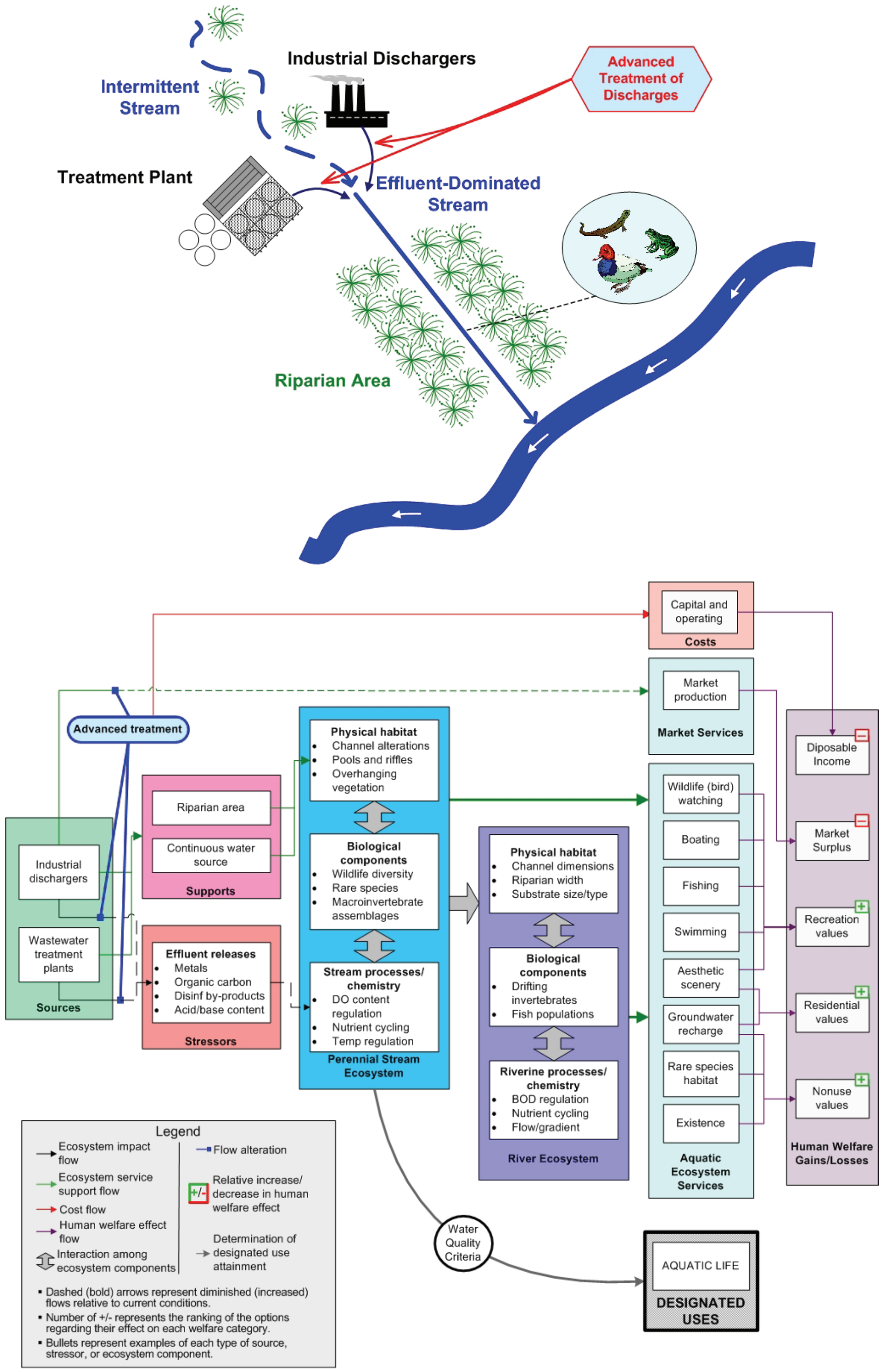


FIGURE 3-18

Management of an Effluent-Dominated Stream:
Option 1: Increased Treatment of Effluent

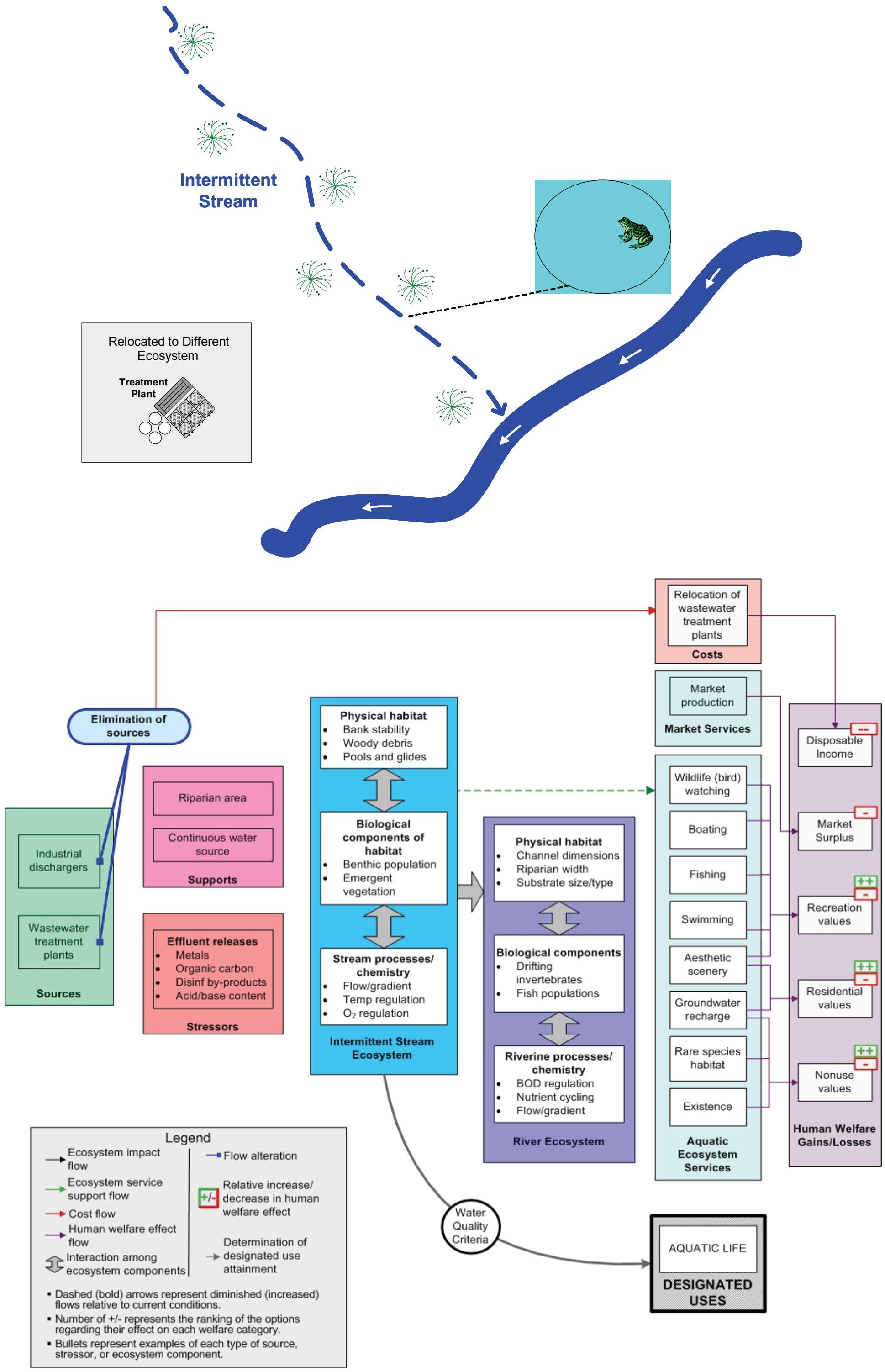


FIGURE 3-19

Management of an Effluent-Dominated Stream:
Option 2: Elimination of Sources of Discharge

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